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6. BASELINE RISK ASSESSMENT

This remedial investigation and baseline risk assessment (RI/BRA) evaluated potential risk to human health and the environment from contaminants buried at the Subsurface Disposal Area (SDA) within the Radioactive Waste Management Complex (RWMC). The risk assessment approach was based on U.S. Environmental Protection Agency (EPA) and Idaho Cleanup Project (ICP) guidance (EPA 1989; Burns 1995). A comprehensive approach was used to evaluate Waste Area Group 7 risk, and cumulative health effects were assessed for all complete pathways for the entire SDA. This risk assessment builds on work presented in the Interim Risk Assessment (IRA) (Becker et al. 1998) and the Ancillary Basis for Risk Analysis (ABRA) (Holdren et al. 2002).

Modeling provided exposure-point concentrations for this RI/BRA, as discussed in detail in Section 5. A source-term model (see Section 5.1) was used to estimate contaminant releases into the environment for the contaminants of potential concern identified in Section 3.4. Additional long-lived radioactive decay products were assessed for completeness. For groundwater pathway analysis, a three-dimensional model was used to estimate potential groundwater concentrations (see Section 5.2). Concentrations derived from modeling biotic intrusion into waste were used to assess cumulative health effects for human health soil exposure pathways and for the ecological risk assessment (see Section 5.5).

Most of Section 6 is directed specifically toward assessing human health risks. All complete exposure pathways were simulated for 1,000 years from hypothetical closure of the SDA in the year 2010. Quantitative results are presented for 1,000 years for all pathways. Because simulated groundwater concentrations for several long-lived radionuclides did not peak within 1,000 years, groundwater was simulated for 10,000 years. Because some contaminants may take a long time to travel to the aquifer, groundwater ingestion results for 10,000 years are presented. Within this section, components of risk analysis are described under the following general headings:

- Section 6.1—Assumptions for the baseline risk assessment

- Section 6.2—Human health exposure assessment

- Section 6.3—Toxicity profiles for human health contaminants of potential concern

- Section 6.4—Human health risk characterization

- Section 6.5—Uncertainty analysis

- Section 6.6—Intruder analysis

- Section 6.7—Ecological risk assessment

- Section 6.8—Summary of the baseline risk assessment

- Section 6.9—References cited in this section.

6.1 Assumptions for Baseline Risk Assessment

Assumptions related to source-release, fate and transport, and biotic modeling are discussed in Section 5. Assumptions discussed in this section are specific to developing baseline human health risk estimates. The U.S. Department of Energy (DOE), the Idaho Department of Environmental Quality (DEQ), and the EPA established occupational and residential scenarios for this RI/BRA (Holdren and Broomfield 2004) based on DOE land-use projections. Land-use projections incorporate an assumption that institutional control will be maintained at the Idaho National Laboratory (INL) Site for at least 100 years (Litus and Shea 2005). The same assumption was adopted as a basis for this RI/BRA, which

applies a 100-year simulated institutional control period assumed to begin in the year 2010. However, because release begins as soon as the first waste is buried, soil concentrations are calculated from 1952, when disposal operations began at the SDA.

Occupational exposure was evaluated for 158 years to encompass SDA operations (i.e., beginning in 1952 and ending in the year 2110) at the end of the simulated 100-year institutional control period. Current monitoring and administrative controls preclude drinking contaminated groundwater during the occupational scenario. Therefore, occupational exposures are limited to soil ingestion, dermal contact with soil, particulate and vapor inhalation, and external (or direct) exposure to ionizing radiation. Section 6.6 evaluates intrusion into the waste.

An additional 900 years of residential exposure was simulated for all complete exposure pathways: particulate and vapor inhalation, soil ingestion, groundwater ingestion, ingestion of homegrown produce, dermal contact with organic chemicals both from soil and while showering, and direct exposure to ionizing radiation.

The following assumptions, in addition to modeling assumptions discussed in Section 5, were incorporated in the RI/BRA:

- Residential receptors will be located at the nearest downgradient edge of the INL Site during the simulated 100-year institutional control period from 2010 to 2110 (see Section 6.4.2.2).

- Residential receptors will be located immediately next to but not on the SDA after the 100-year simulated institutional control period. The receptor will be exposed to average SDA soil concentrations and maximum groundwater concentrations outside the SDA.

- Occupational receptors are located on the SDA.

- Nonradioactive contaminants do not degrade. The only mechanisms that reduce risk over time are radioactive decay and contaminant concentrations diminishing through transport. This assumption simplifies modeling and produces conservative results for carbon tetrachloride because toxicity of the decay products is less than the toxicity of carbon tetrachloride.

6.2   Human Health Exposure Assessment

In the human health exposure assessment, receptor intake of contaminants of potential concern was quantified for all complete exposure pathways. The assessment consisted of estimating magnitudes, frequencies, durations, and exposure routes of contaminants of potential concern to humans. The following activities were performed as part of the exposure assessment:

- Identifying and characterizing exposed populations

- Evaluating exposure pathways

- Estimating contaminant concentrations at points of exposure for soil, air, and groundwater

- Estimating contaminant intakes.

Section 6.2.1 discusses the first two tasks, Section 6.2.2 discusses media concentrations, and Section 6.2.3 quantifies exposures.

6.2.1 Exposure Scenarios and Conceptual Site Model

Occupational and residential scenarios are addressed quantitatively. For convenience, both scenarios are divided into two time periods: during institutional control and after institutional control. Institutional control is assumed to last 100 years from hypothetical closure of the facility in 2010.

The INL Site boundary is the receptor location for the residential scenario during institutional control. Because of the distance from the SDA to the INL Site boundary, groundwater ingestion is the only complete pathway. Residential groundwater ingestion at the INL Site boundary during the 100-year institutional control period is not likely, but is used to bound the groundwater risk for the institutional control period. After the assumed loss of institutional control, the receptor location moves to the SDA boundary, and surface exposure pathways are complete as well. All pathway risks are computed for 1,000 years. Because some contaminants take a long time to reach the aquifer, groundwater ingestion pathway risks are presented up to 10,000 years.

For the occupational receptor, the location is on the SDA for both time periods. The occupational scenario does not have a groundwater ingestion pathway. The major difference between the two time periods for the occupational scenario is that the SDA is allowed to return to native plant and animal communities after assumed loss of institutional control, allowing larger amounts of contaminants to be brought to the surface by biota and increasing potential exposures. All pathway risks are computed for 1,000 years. Intrusion into waste is evaluated in Section 6.6.

The human health conceptual site model in Figure 6-1 shows complete exposure pathways for residential scenarios. Groundwater, air, and soil pathways are complete for residential exposures. The conceptual site model also shows some complexities in the exposure scenarios (e.g., contaminated groundwater is directly ingested and also is used to irrigate crops, shower, and cook).

The conceptual site model shows that the groundwater pathway is incomplete for the occupational scenario because current operational procedures preclude using contaminated water as a drinking source. Complete occupational scenario exposure pathways include particulate inhalation, soil ingestion, and direct exposure to ionizing radiation.

The RI/BRA addresses potential impacts of waste buried in the SDA, but does not address past operational or flooding releases to the surface. Any material released during operations would have been reburied by recontouring at the SDA. The Operable Unit 7-05 evaluation showed that no contaminants are released above screening levels through surface water (Burns, Loehr, and Waters 1993). Because perched water is short-lived at the SDA, it is not considered a viable drinking water source. Therefore, perched water is an incomplete pathway for the analysis.

This RI/BRA evaluates the following human health exposure routes (see Figure 6-1):

- Ingestion of soil

- Inhalation of fugitive dust

- Inhalation of volatiles (includes residential scenario indoor use of groundwater)

- External exposure to radiation

- Dermal absorption from soil (organic contaminants only)

- Ingestion of groundwater (residential scenario only)

- Ingestion of homegrown produce (residential scenario only)

- Dermal absorption of contaminants in groundwater (residential scenario only).

Primary Sources

Primary Release Mechanisms

Secondary Sources

Secondary Release Mechanisms

Tertiary Sources

Tertiary Release Mechanisms

Exposure Routes

Pits, trenches, pads (drums, boxes, activated metals)

Container failure
Corrosion
Leaching
Volatilization
Liquid disposal

Overburden
Backfill soil
Asphalt pad
Surficial sediments

Biotic uptake
Volatilization
Leaching

Surface fines
Basalt
Sedimentary interbeds
Sediment-filled fractures
Shallow, disontinuous perched water in vadose zone
Snake River Plain Aquifer (groundwater)

Dust suspension
Volatilization
Leaching

Air inhalation
Direct exposure
Groundwater ingestion
Food ingestion
Soil ingestion
Meat and dairy ingestion

Acid Pit

Liquid disposal

Overburden
Surficial sediments

Soil vaults

Container failure
Corrosion
Diffusion
Leaching

Overburden
Surficial sediments

	Occupational	Residential
Dermal (soil)	●	●
Soil ingestion	●	●
Dermal (water)		●
Crop ingestion		●
Direct exposure	●	●
Groundwater ingestion		●
Inhalation of dust	●	●
Inhalation of volatiles	●	●

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Figure 6-1. Human health conceptual site model.

6.2.2   Media Concentrations

Media concentrations were estimated by the modeling discussed in Section 5. The DOSTOMAN biotic transport code was used to estimate average concentrations of contaminants of potential concern at the surface and at shallow depths to 2.2 m (7.2 ft) below ground surface for the entire SDA. The DUST-MS source-release code was used to simulate release of contaminants of potential concern from buried waste into the subsurface beneath the SDA. Resulting fluxes were input to the subsurface model, TETRAD. The subsurface model simulated vadose zone transport and emulated fluxes of contaminants of potential concern into the aquifer. TETRAD also was used to estimate concentrations and transport of contaminants of potential concern in the aquifer.

Estimated media concentrations were used directly (e.g., groundwater concentrations for the groundwater ingestion route) and indirectly (e.g., developing media concentrations for other pathways such as air concentrations) to assess risk. The development of media concentrations for each exposure route is summarized in the following sections. Table 6-1 presents maximum soil and groundwater concentrations and the years of predicted occurrences of maximum concentrations. The maximum soil concentration at any time is listed (i.e., the maximum can occur before the end of institutional control in the year 2110). If maximum soil concentration occurs before the year 2110, it is used to evaluate the occupational scenario. Based on the exposure assessment (see Section 6.2.1), soil concentrations in Table 6-1 are the maximums on the SDA, and groundwater concentrations are the maximums predicted outside the SDA fence line after the year 2110. Figures in Section 6.4.3 illustrate simulated surface soil and groundwater concentrations (i.e., the basis for exposure-point concentrations used in risk calculations).

Table 6-1. Simulated maximum soil and groundwater concentrations for contaminants of potential concern and associated decay-chain members.

Contaminant	Maximum Soil Concentration[a]	Maximum Soil Concentration (year[b])	Maximum Groundwater Concentration[c]	Maximum Groundwater Concentration (year[d])
Ac-227	4.35E-05	2317	5.30E-02	3010
Am-241	2.49E+03	2609	6.80E-08	3010
Am-243	5.70E-03	3010	1.29E-09	3010
C-14	8.83E-03	1974	1.86E+02	2133
Cl-36	1.37E-09	2005	2.12E+01	2395
Cs-137	1.44E-02	2037	NA	NA
I-129	1.14E-08	2004	1.31E+01	2111
Nb-94	7.90E-03	3010	NA	NA
Np-237	2.78E-01	2660	6.53E-02	3010
Pa-231	3.48E-05	2299	8.17E-02	3010
Pb-210	3.10E+00	3010	1.02E-05	3010
Pu-238	2.30E+00	2277	6.10E-19	2920
Pu-239	4.77E+03	3010	5.19E-10	3010
Pu-240	9.99E+02	3010	1.28E-10	3010
Ra-226	2.85E+00	3010	1.30E-05	3010
Ra-228	2.40E-01	3010	1.97E-09	3010
Sr-90	1.70E+02	2024	NA	NA
Tc-99	3.68E-01	1988	2.71E+03	2111

Table 6-1. (continued).

Contaminant	Maximum Soil Concentration[a]	Maximum Soil Concentration (year[b])	Maximum Groundwater Concentration[c]	Maximum Groundwater Concentration (year[d])
Th-228	5.85E+04	3010	NA	NA
Th-229	2.42E-03	3010	2.64E-02	3010
Th-230	1.12E-02	3010	3.01E-04	3010
Th-232	2.36E-01	3010	2.82E-09	3010
U-233	5.67E-03	2300	2.90E+00	3010
U-234	1.66E-01	2299	3.97E-01	3010
U-235	1.28E-02	2300	1.19E-01	3010
U-236	4.90E-03	2345	6.24E-01	3010
U-238	3.89E-01	2298	5.52E-01	3010
Carbon tetrachloride	6.01E-04	1984	3.07E-01	2130
1,4-Dioxane	7.05E-03	1971	1.69E-01	2111
Methylene chloride	1.13E-06	1972	5.85E-02	2245
Nitrate	2.67E-01	1980	6.47E+01	2111
Tetrachloroethylene	6.43E-05	1982	6.64E-02	2145
Trichloroethylene	7.43E-05[e]	1984	3.80E-02 [e]	2130

a. Soil concentration units are pCi/g for radionuclides and mg/kg for nonradionuclides.
b. Peak concentrations that occur before the year 2110, the end of the simulated institutional control period, are used to evaluate the current occupational exposure scenario, and calculated concentrations in the year 2110 are used to assess future occupational and residential exposure scenarios.
c. Groundwater concentration units are pCi/L for radionuclides and mg/L for nonradionuclides.
d. Based on land-use assumptions and the exposure assessment in Section 6.2.1, reported maximum groundwater concentrations are outside the perimeter of the Subsurface Disposal Area and occur after the year 2110.
e. Carbon tetrachloride values were scaled to estimate values for trichloroethylene. A complete analysis will be performed for the feasibility study.

6.2.2.1   Soil Ingestion. Typically, incidental soil ingestion occurs when dust particles are inhaled, expectorated, and swallowed. Food, water, and other edible materials exposed to contaminated air, tools, or hands also can introduce ingested contamination. The DOSTOMAN biotic model was used to predict surface soil concentrations in the SDA for estimating risk from ingesting contaminated soil. For occupational exposure, 25-year average concentrations were used; for residential exposure, 30-year averages were used.

6.2.2.2   Inhalation of Fugitive Dust. Soil concentrations produced by DOSTOMAN were used to derive concentrations of contamination in the air caused by suspended dust, as shown in Equation (6-1):

$$C_{air} = RC_{soil} \tag{6-1}$$

where

C_{air} = particulate concentration in the air (mg/m^3 or pCi/m^3)

R = airborne respirable particulate matter (mg/m^3) (measured value of 1.5E-08 kg/m^3 from PM10 monitoring at RWMC)

C_{soil} = average soil concentration (mg/kg or pCi/kg).

6.2.2.3   Inhalation of Volatiles. This assessment used the vapor transport model developed to support the Organic Contamination in the Vadose Zone (OCVZ) Project operation to compute vapor transport and plume concentrations. The subsurface model, TETRAD, computed the flux of the volatile contaminants through the ground surface. The volatile flux results from vapor-phase diffusion and barometric pumping effects. The flux was input into a "box model" to compute the air concentration used to assess risk from inhaling volatiles. Equation (6-2) is used to represent air concentration resulting from the flux of volatile contaminants:

$$C_{air} = \frac{FLX}{MH \times W \times WS} \times CF1 \times CF2 \qquad\qquad (6\text{-}2)$$

where

C_{air} = air concentration (mg/m^3 or pCi/m^3)

FLX = volatile flux (kg/day or pCi/day)

MH = mixing height (2 m)

W = facility width (181 m)

WS = wind speed (2.83 m/second)

CF1 = conversion factor (1 day/86,400 seconds)

CF2 = conversion factor (1E+06 mg/kg or 1 pCi/pCi).

6.2.2.4   External Radiation Exposure. Exposure to ionizing radiation is caused by concentrations in surface soil. Average surface concentrations predicted by the DOSTOMAN biotic model were used to estimate potential exposure.

6.2.2.5   Dermal Absorption from Organic Contaminants in Soil. Concentrations of organic contaminants in soil were computed directly by TETRAD and used in the exposure calculations. The largest volatile organic compound (VOC) concentration in any grid in the SDA was used for total SDA risk calculation.

6.2.2.6   Residential Groundwater Ingestion. TETRAD was used to estimate aquifer concentrations anywhere in the modeling domain. Maximum predicted groundwater concentrations along the INL Site boundary were used to quantify potential exposure to contaminated groundwater during the simulated 100-year institutional control period. Estimated groundwater concentrations, concurrent with maximum groundwater risk for all contaminants, were used to quantify potential exposure for the hypothetical future residential scenario.

6.2.2.7   Residential Ingestion of Homegrown Produce. Concentrations of contaminants in homegrown produce were computed using both soil and groundwater concentrations. Groundwater concentrations were used to mimic produce irrigated with contaminated groundwater. The methodology for determining crop concentrations is detailed in Burns (1996), an INL report on the food-crop-ingestion exposure route.

6.2.2.8   Residential Dermal Absorption of Contaminants in Groundwater. Contaminant concentrations predicted by the subsurface model were used directly to address dermal exposure to contaminated groundwater.

6.2.2.9   *Residential Inhalation of Volatiles from Indoor Use of Groundwater.*
Equation (6-3) was used to compute concentrations of contaminants in indoor air from using indoor water:

$$C_{air} = C_{water} \, VF \tag{6-3}$$

where

C_{air} $\quad=\quad$ concentration in air (mg/m^3)

C_{water} $\quad=\quad$ concentration in water (mg/L)

VF $\quad=\quad$ volatilization factor (EPA [1991] value of 0.5 L/m^3).

A single volatilization factor is used for all VOCs, based on EPA Region 10 guidance (EPA 1991).

6.2.3   Quantification of Exposure

Contaminant intake depends on the ingestion or contact rate with the contaminated media. For radioactive contaminants, exposure was described as a total lifetime intake (in pCi). For hazardous contaminants, exposure was quantified using an intake rate (in mg/kg/day). The following subsections present methods used to compute intake for each human health exposure pathway.

6.2.3.1   *Soil Ingestion.* Equation (6-4) was used to compute intake from incidental soil ingestion. In accordance with EPA guidance (EPA 1989), the first 6 years of exposure were assessed at a higher rate to account for long-term average daily ingestion rates for children. For radionuclides, the denominator (BW × AT) was removed from the equation. Default values for Equation (6-4) were taken from Track 2 guidance (DOE-ID 1994).

$$\text{Intake} = C_{soil} \times \frac{\left[\dfrac{IR_c \times EF \times ED_c}{BW_c}\right] + \left[\dfrac{IR_a \times EF \times ED_a}{BW_a}\right]}{AT \times CF} \tag{6-4}$$

where

Intake = contaminant intake (mg/kg/day or pCi)

and

Parameter		Occupational Exposure Value	Residential Exposure Value
C_{soil}	= contaminant concentration in soil (mg/kg or pCi/g)	contaminant dependent	contaminant dependent
CF	= conversion factor	10^{-6} kg/mg nonradionuclide or 10^{-3} g/mg radionuclide	10^{-6} kg/mg nonradionuclide or 10^{-3} g/mg radionuclide
IR_c	= child ingestion rate of soil (mg/day)	NA	200
IR_a	= adult ingestion rate of soil (mg/day)	50	100

	Parameter	Occupational Exposure Value	Residential Exposure Value
EF	= exposure frequency (day/year)	250	350
ED_c	= child exposure duration (year)	NA	6
ED_a	= adult exposure duration (year)	25	24
BW_c	= child body weight (kg)	NA	15
BW_a	= adult body weight (kg)	70	70
AT	= averaging time (day)	9.13E+03 (noncarcinogenic) 2.55E+04 (carcinogenic)	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

6.2.3.2 *Inhalation of Fugitive Dust.* Intake from inhalation can be computed similarly to intake from soil ingestion (i.e., contaminant air concentration was adjusted by factors to account for type of exposure [residential or occupational] and was compared to the unit risk concentration). Equation (6-5) was used to compute intake from inhalation. For radionuclides, the denominator (BW × AT) was removed from the equation. Default values for Equation (6-5) were taken from Track 2 guidance (DOE-ID 1994).

$$\text{Intake} = \frac{C_{air} \times IR \times EF \times ED}{BW \times AT} \qquad (6\text{-}5)$$

where

Intake = contaminant intake (mg/kg/day or pCi)

and

	Parameter	Occupational Exposure Value	Residential Exposure Value
C_{air}	= contaminant concentration in air (mg/m^3 or pCi/m^3)	contaminant dependent	contaminant dependent
IR	= inhalation rate of air (m^3/day)	20	20
EF	= exposure frequency (day/year)	250	350
ED	= exposure duration (year)	25	30
BW	= body weight (kg)	70	70
AT	= averaging time (day)	9.13E+03 (noncarcinogenic) 2.55E+04 (carcinogenic)	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

6.2.3.3 *Inhalation of Volatiles.* Methodology and parameter values for computing intake from inhalation of volatiles are the same as for computing intake from inhalation of fugitive dust.

6.2.3.4   External Radiation Exposure. Equation (6-6) was used to compute total exposure for radionuclides. Default values for Equation (6-6) were taken from Track 2 guidance (DOE-ID 1994).

$$Exposure = C_{soil} \times ET \times EF \times ED \times CF \qquad (6\text{-}6)$$

where

   Exposure = contaminant intake (pCi/year/g)

and

Parameter			Occupational Exposure Value	Residential Exposure Value
C_{soil}	=	contaminant concentration in soil (pCi/g)	contaminant dependent	contaminant dependent
ET	=	exposure time (hour/day)	8	24
EF	=	exposure frequency (day/year)	250	350
ED	=	exposure duration (year)	25	30
CF	=	conversion factor	1.14E−04 year/hour	1.14E−04 year/hour.

6.2.3.5   Dermal Absorption of Organic Contaminants from Soil. The absorbed dose of a contaminant is computed based on methodology for the dermal exposure route. Toxicity values provided in the Integrated Risk Information System database (EPA 2006) and other EPA sources are developed for the ingestion exposure route. Toxicity values are based on the amount of contaminant ingested, not the amount that actually enters the bloodstream. Only some fraction of the contaminant is absorbed through the gastrointestinal tract after being ingested. The fraction absorbed through the gastrointestinal tract can be used to modify the oral toxicity for use in the dermal exposure route. For organic contaminants, the fraction absorbed through the gastrointestinal tract is large and is conservatively assumed to be in unity in this analysis. No scaling of toxicity or intake is required.

   Equation (6-7) was used to compute absorbed dose for dermal contact with contaminated soil. Default values for Equation (6-7) were taken from EPA Region 10 guidance (EPA 1991).

$$AD = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \qquad (6\text{-}7)$$

where

   AD = adsorbed dose (mg/kg/day)

and

Parameter			Occupational Exposure Value	Residential Exposure Value
CS	=	contaminant concentration in soil (mg/kg)	contaminant dependent	contaminant dependent
CF	=	conversion factor	10^{-6} kg/mg	10^{-6} kg/mg

	Parameter	Occupational Exposure Value	Residential Exposure Value
SA	= skin surface area (cm^2/event)	5,000	5,000
AF	= soil-to-skin adherence factor (mg/cm^2)	1	1
ABS	= absorption factor (unitless)	Contaminant dependent	Contaminant dependent
EF	= exposure frequency (event/year)	250	350
ED	= exposure duration (year)	25	30
BW	= body weight (kg)	70	70
AT	= averaging time (day)	9.13E+03 (noncarcinogenic) 2.55E+04 (carcinogenic)	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

6.2.3.6   *Residential Groundwater Ingestion.* Equation (6-8) was used to calculate intake from groundwater ingestion. For radionuclides, the denominator (BW × AT) is removed from the equation. Default values for Equation (6-8) were taken from Track 2 guidance (DOE-ID 1994).

$$\text{Intake} = \frac{C_{GW} \times IR \times EF \times ED}{BW \times AT}$$
(6-8)

where

Intake = contaminant intake (mg/kg/day or pCi)

and

	Parameter	Occupational Exposure Value	Residential Exposure Value
C_{GW}	= contaminant concentration in groundwater (mg/L or pCi/L)	NA	contaminant dependent
IR	= ingestion rate of groundwater (L/day)	NA	2
EF	= exposure frequency (day/year)	NA	350
ED	= exposure duration (year)	NA	30
BW	= body weight (kg)	NA	70
AT	= averaging time (day)	NA	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

6.2.3.7   *Residential Ingestion of Homegrown Produce.* Equation (6-9) was used to calculate the intake from ingesting homegrown produce. Burns (1996) provided ingestion rates. For radionuclides, the denominator (BW × AT) was removed from the equation. Default values for Equation (6-9) were taken from Track 2 guidance (DOE-ID 1994).

$$\text{Intake} = \frac{C_{Produce} \times IR \times EF \times ED \times CF}{BW \times AT} \tag{6-9}$$

where

Intake = contaminant intake (mg/kg/day or pCi)

and

Parameter			Occupational Exposure Value	Residential Exposure Value
$C_{produce}$	=	contaminant concentration in produce (mg/kg or pCi/g)	NA	contaminant dependent
IR	=	ingestion rate of produce (g/day)	NA	2.76E–01 g/kg/day (nonradionuclide) 1.67E–01 g/day (radionuclide)
EF	=	exposure frequency (day/year)	NA	350
ED	=	exposure duration (year)	NA	30
CF	=	conversion factor (kg/g)	NA	10^{-3} (nonradionuclide only)
BW	=	body weight (kg)	NA	70
AT	=	averaging time (day)	NA	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

6.2.3.8   *Residential Dermal Absorption of Organic Contaminants in Groundwater—*
Equation (6-10) was used to compute dermal absorption from contact with contaminated groundwater. Default values for Equation (6-10) were taken from EPA Region 10 guidance (EPA 1991):

$$AD = \frac{DA_{event} \times SA \times EF \times ED}{BW \times AT} \tag{6-10}$$

where

AD = absorbed dose (mg/kg/day)

and

Parameter			Occupational Exposure Value	Residential Exposure Value
DA_{event}	=	amount absorbed per event (mg/cm^2/event)	NA	see below
SA	=	skin surface area (cm^2)	NA	20,000

Parameter		Occupational Exposure Value	Residential Exposure Value
EF	= exposure frequency (event/year)	NA	350
ED	= exposure duration (year)	NA	30
BW	= body weight (kg)	NA	70
AT	= averaging time (day)	NA	1.10E+04 (noncarcinogenic) 2.55E+04 (carcinogenic).

Equation (6-11) provides the amount absorbed per event. Default values were taken from EPA Region 10 guidance (EPA 1991). Table 5-8 of the EPA Dermal Exposure Assessment (EPA 1992a) provides the values of K_p and τ shown in Equation (6-11):

$$DA_{event} = 2 \times K_P \times C_{water} \times CF \times \sqrt{\frac{6 \times \tau \times t_{event}}{\pi}} \tag{6-11}$$

where

DA_{event} = amount absorbed per event (mg/cm^2/event)

and

Parameter		Occupational Exposure Value	Residential Exposure Value
K_p	= permeability coefficient for contaminant through skin (cm/hour)	NA	contaminant specific
C_{water}	= concentration in water (mg/L)	NA	contaminant specific
CF	= conversion factor	NA	1E−03 L/cm^3
τ	= lag time (hour/event)	NA	contaminant specific
t_{event}	= event time (hour/event)	NA	0.17.

A much larger skin area is used for dermal exposure to groundwater while showering (see Equation [6-10]) compared to soil exposure (see Equation [6-7]) because the entire body is exposed during showering while only the skin not covered by clothes (e.g., face and hands) is exposed to soil.

6.2.3.9   *Residential Inhalation of Volatiles from Indoor Use of Groundwater.* Intake from indoor use of groundwater was computed using the same methodology and parameter values as for inhalation of volatiles. The indoor air concentration is derived from the groundwater concentration and EPA Region 10-approved volatilization factors (EPA 1991). The exposure parameters used are the same for inhalation of fugitive dust.

6.3 Toxicity Profiles for Human Health Contaminants of Potential Concern

A toxicity assessment was conducted to identify potential adverse effects of Waste Area Group 7 contaminants of potential concern and to compile toxicity values (i.e., numerical expressions of dose-response relationships) for use in the RI/BRA. Reference doses and reference concentrations are used to evaluate noncarcinogenic effects. Unit risk values and slope factors apply to carcinogenic effects. Each toxicity value is specific to both a particular substance and to the exposure pathway. The majority of toxicity values for this assessment were obtained from the EPA Integrated Risk Information System database (EPA 2006) and the Health Effects Assessment Summary Tables (EPA 2001). Data values extracted from the Integrated Risk Information System database and Health Effects Assessment Summary Tables were verified or modified to reflect changes and updates since the ABRA (Holdren et al. 2002).

Each human health contaminant of potential concern is classified as either a chemical or a radionuclide. Potential carcinogenic and noncarcinogenic effects were considered for the four chemical contaminants of potential concern. Only carcinogenic effects were considered for the 20 radioactive contaminants of potential concern.

For noncarcinogenic effects, Table 6-2 shows descriptions of critical effects, oral reference doses, inhalation reference concentrations, and maximum contaminant levels (MCLs). A critical effect, as defined by EPA (1996), is the first adverse effect of a contaminant or its known precursor that occurs as the dose rate increases (i.e., the first observable symptom that results from an exposure).

Weight-of-evidence classes, oral slope factors, inhalation unit risk values, and MCLs are used to assess carcinogenic toxicity for chemicals. The EPA groups substances to describe carcinogenicity according to the weight of evidence supporting the classification. Groups A, B1, B2, and C are described as follows:

- **Group A**—Direct evidence is sufficient to classify the substance as a probable human carcinogen

- **Group B1**—Direct evidence of carcinogenesis is sufficient in animals, with some supporting human data, to classify the substance as a probable human carcinogen

- **Group B2**—Evidence is sufficient of carcinogenesis in animals, with some human data, but of lesser quality than in Group B1, to classify the substance as a possible human carcinogen

- **Group C**—Some carcinogenesis in animals and humans is evident, but data are not sufficient to assess probability of carcinogenesis.

All radionuclides are classified as Group A carcinogens.

6.3.1 Chemicals

Carbon tetrachloride, methylene chloride, nitrate, and tetrachloroethylene were evaluated for noncarcinogenic effects based on availability of toxicity data needed for risk calculations (see Table 6-2). Carbon tetrachloride, 1,4-dioxane, methylene chloride, tetrachloroethylene, and trichlorethylene also were evaluated for carcinogenic effects. Table 6-3 provides the EPA weight-of-evidence classification and available oral slope factors, inhalation unit risks, and MCLs for chemical carcinogens. Potential toxic effects associated with the evaluated exposure routes and sources of toxicity values used in the toxicity assessment are described in the following sections.

Table 6-2. Toxicity values for quantitatively evaluated noncarcinogenic contaminants of potential concern.

Chemical	Critical Effect	Chronic[a] Oral Reference Dose (mg/kg/day)	Chronic Oral Reference Dose Uptake Factor	Chronic[a] Inhalation Reference Concentration (mg/m^3)	Chronic Inhalation Reference Concentration Uncertainty Factor	Maximum Concentration Level[b] (mg/L)
Carbon tetrachloride	Liver lesions	7.0E-04	1.0E+03	ND	ND	5.0E-03
1,4-Dioxane	Toxicity to liver and kidneys in humans and animals	ND	ND	ND	ND	ND
Methylene chloride	Liver toxicity	6.0E-02	1.0E+02	3.0E+00[c]	1.0E+02	5.0E-03
Nitrate	Early clinical signs of hemoglobin in oxidized state in the blood	1.6E+00	1.0E+00	ND	ND	1.0E+01[d]
Tetrachloroethylene	Liver toxicity in mice and weight gain in rats	1.0E-02	1.0E+03	ND	ND	5.0E-03
Trichloroethylene	Enlargement and toxicity in rodent liver and kidney and central nervous system symptoms	ND	ND	6.0E-01[e]	ND	5.0E-03

a. Values are from the Integrated Risk Information System database (EPA 2006), except where noted.
b. MCLs are obtained from "National Primary Drinking Water Regulations" (40 CFR 141) and EPA (1996).
c. Toxicity value is from the Health Effects Assessment Summary Tables (EPA 2001).
d. MCL for nitrate is 10 mg/L as nitrogen.
e. No EPA toxicity values are available. The value is from the Office of Environmental Health Hazard Assessment database (OEHHA 2003) for the State of California.

EPA = U.S. Environmental Protection Agency
MCL = maximum contaminant level
ND = no data are available

Table 6-3. Toxicity values for quantitatively evaluated chemical carcinogens.

Chemical	Weight of Evidence[a]	Oral Slope Factor[a] $(mg/kg/day)^{-1}$	Inhalation Unit Risk[a] $(mg/m^3)^{-1}$	Maximum Contaminant Level[b] (mg/L)
Carbon tetrachloride	B2	1.3E-01	1.5E-02	5.0E-03
1,4-Dioxane	B2	1.1E-02	ND	ND
Methylene chloride	B2	7.5E-03	4.7E-04	5.0E-03
Tetrachloroethylene	B2	5.4E-04[c]	5.9E-03[c]	5.0E-03
Trichloroethylene	ND[d]	1.3E-02[c]	2.0E-03[c]	5.0E-03

a. Values are from the Integrated Risk Information System database (EPA 2006).
b. Maximum contaminant levels are from "National Primary Drinking Water Regulations" (40 CFR 141) and EPA (1996).
c. No EPA toxicity values are available. The value is from OEHHA (2003) for the State of California.
d. Weight-of-evidence classification is being reevaluated by EPA (EPA 2006).

EPA = U.S. Environmental Protection Agency
ND = no data are available

6.3.1.1 *Carbon Tetrachloride.* Exposure to high levels of carbon tetrachloride can be fatal. The critical effect of carbon tetrachloride is liver lesions (EPA 2006). The most immediate harmful effects are to the central nervous system. Other common effects include headaches, dizziness, nausea, and vomiting. In severe cases, stupor, coma, and permanent damage to nerve cells can occur (ATSDR 1989).

The liver is sensitive to carbon tetrachloride, and liver damage can result from either acute or chronic exposure. In mild exposure cases, the liver becomes swollen and tender, and fat tends to build up inside the tissue. In severe cases, many cells may be killed, leading to decreased liver function. Carbon tetrachloride can be absorbed through the skin in sufficient quantities to cause liver damage (ATSDR 1989).

Some reports noted the occurrence of liver cancer in individuals exposed to carbon tetrachloride fumes, both acutely and for long periods. Studies show that prolonged administration of high levels of carbon tetrachloride by oral or subcutaneous routes can induce liver tumors in rats, mice, and hamsters (ATSDR 1989). Though no studies have established that inhalation exposure to carbon tetrachloride poses a risk of cancer, oral and parenteral exposure in animals have shown evidence for liver carcinogenicity. Because similar noncarcinogenic effects are observed in the liver following oral and inhalation exposure, carcinogenic effects are likely to be similar for both types of exposure (i.e., inhalation exposure could lead to liver cancer) (ATSDR 1989).

Kidneys also are sensitive to carbon tetrachloride. Kidney disease and inflammation leading to kidney failure and death are common effects in humans following inhalation exposure. Abnormally high serous fluid in the lungs (i.e., pulmonary edema) commonly occurs in humans exposed to high levels of carbon tetrachloride in air. Ingestion of carbon tetrachloride has been associated with decreased function of the central nervous system, kidney and lung injury, and marked hepatoxicity.

The EPA has classified carbon tetrachloride as a B2 human carcinogen for both ingestion and inhalation (EPA 1996). The oral slope factor for carbon tetrachloride is 1.3E-01 $(mg/kg/day)^{-1}$, and the inhalation unit risk is 1.5E-02 $(mg/m^3)^{-1}$ (EPA 2006). The inhalation slope factor assumes 40% absorption of carbon tetrachloride. The carcinogenic toxicity value is medium because, though several studies indicate tumor incidence and death are caused by carbon tetrachloride, all the studies are deficient in some respect.

Evaluation of noncarcinogenic effects after ingestion of carbon tetrachloride is based on 7.0E-04 mg/kg/day, an EPA-established chronic reference concentration (EPA 2006). The potential for noncarcinogenic effects from inhalation exposure to carbon tetrachloride is not evaluated because data are not sufficient for EPA to develop a reference concentration.

6.3.1.2   *1,4-Dioxane.* The critical effect of 1,4-dioxane is toxicity to the liver and kidneys in both humans and animals (EPA 2006 [see CASRN 123-91-1]); ATSDR 2004). Human fatalities are associated with acute accidental exposure to high amounts of 1,4-dioxane vapors. However, several studies of workers exposed to 1,4-dioxane for long periods did not show significant chronic health effects. Short-term exposure of volunteers to low concentrations (50 ppm) of 1,4-dioxane vapors resulted in irritation of the eyes, nose, and throat. Effects of 1,4-dioxane on reproductive function or immunocompetence have not been studied in either humans or animals.

No conclusive evidence was found to indicate that 1,4-dioxane causes cancer in humans (ATSDR 2004). However, rats that consumed drinking water containing 1,4-dioxane for most of their lives developed cancer of the liver and nasal cavity. Though evidence of carcinogenicity in humans is inadequate, evidence of carcinogenicity in experimental animals is sufficient to prompt the EPA to identify 1,4-dioxane as a B2 human carcinogen (EPA 2006).

The EPA has not established a reference dose for chronic oral exposure to 1,4-dioxane, but recommends using a slope factor of 1.1E-02/mg/kg/day for quantitative estimation of carcinogenic risk from oral exposure (EPA 2006). A quantitative estimate of carcinogenic risk from inhalation exposure to 1,4-dioxane is currently not available.

A recent EPA review of the carcinogenic potency of 1,4-dioxane concluded that observed increases in risk may not be associated with genotoxic effects (ATSDR 2004). Therefore, the carcinogenicity of 1,4-dioxane is presently being reassessed using the Integrated Risk Information System database (EPA 2006).

6.3.1.3   *Methylene Chloride.* Liver toxicity comprises the critical effect of methylene chloride (EPA 2006). Inhalation is the principal route of human exposure to methylene chloride. Evaluation of pulmonary uptake in humans indicates that 70 to 75% of inhaled methylene chloride vapor is absorbed. As for absorption of other lipophilic organic vapors, methylene chloride absorption appears to be influenced by factors other than the vapor concentration. Increased physical activity and higher body fat increase the amount of methylene chloride absorbed by the body (ATSDR 1993).

Effects from inhalation of methylene chloride include headaches, giddiness, stupors, irritability, numbness, and tingling in the limbs. Irritation to the eyes and upper respiratory passages occurs at higher doses. In severe cases, toxic brain disease with hallucinations, effusion of fluid into the alveoli and interstitial spaces of the lungs, coma, and death have been observed. Cardiac arrhythmias have been produced in animals but have not been common in humans. Exposure to methylene chloride may cause elevated carboxyhemoglobin levels that may be significant in smokers, workers with anemia or heart disease, and those exposed to carbon monoxide (Sittig 1985).

The central nervous system is affected adversely in humans and animals at exposure levels of 500 ppm or higher. Noted effects from these exposure levels were decreased visual and auditory functions; however, these effects were reversible once exposure ceased. Similarly, psychomotor performance (e.g., reaction time, hand precision, and steadiness) was impaired. In addition, alterations in visually evoked responses were observed in humans exposed to higher levels of methylene chloride (ATSDR 1993).

The EPA has classified methylene chloride as a B2 human carcinogen for both ingestion and inhalation (EPA 2006). The oral slope factor for methylene chloride is 7.5E-03 $(mg/kg/day)^{-1}$, and the inhalation unit risk is 4.7E-04 $(mg/m^3)^{-1}$ (EPA 2006). Confidence in the toxicity values is medium for methylene chloride because important uncertainties remain about pharmacokinetics, pharmacodynamics, and mechanisms of carcinogenicity.

Evaluating noncarcinogenic effects after ingestion of methylene chloride is based on a chronic reference concentration of 6.0E-02 mg/kg/day (EPA 2006). The inhalation reference concentration for methylene chloride is 3.0E+00 mg/m^3 (EPA 1995). The uncertainty factor of 100 accounts for both expected intraspecies and interspecies variability to the toxicity of this chemical. Overall confidence in the oral reference concentration is medium because the associated database is rated medium to low, based on the limited number of studies.

6.3.1.4   Nitrate. The critical effect of nitrate is early clinical signs of the presence of hemoglobin in an oxidized state in the blood (EPA 2006). Because nitrate can have adverse effects, sodium and potassium nitrate are evaluated for noncarcinogenic effects. The nitrate form of nitrogen is of concern because the ion is highly soluble in water; this characteristic enhances leaching, diffusion, and environmental mobility in soil and water.

Nitrate in the environment is of primary concern because nitrate can reduce to nitrite in biological systems. Nitrite is formed from nitrate by certain microorganisms in the alimentary tract and in soil, water, and sewage (Amdur, Doull, and Klassen 1991). Nitrate reduction to nitrite can occur under certain conditions in the stomach as well as in saliva. Nitrite acts in the blood to oxidize hemoglobin to methemoglobin, which cannot conduct oxygen to the tissues. This condition, known as methemoglobinemia, is caused in humans by high levels of nitrite or, indirectly, by excessive levels of nitrate. Nitrate toxicity can result from ingestion of water and vegetables high in nitrate (EPA 2006). Newborns (i.e., 0 to 3 months) are more susceptible to nitrate toxicity than are adults. The increased susceptibility of newborns has been attributed to a high intake per unit weight, presence of nitrate-reducing bacteria in the upper gastrointestinal tract, condition of the mucosa, and greater ease of oxidation of fetal hemoglobin.

Other effects associated with ingestion of nitrate include hypotension, relatively rapid heartbeat, respiratory dysfunction (from methemoglobinemia), headache, nausea, vomiting, and diarrhea. Exposure to nitrate resulting in convulsions following severe intoxication has been reported.

Little scientific basis supports conclusions about the relationship between nitrate concentrations and the carcinogenic potential (EPA 2006). The EPA does not classify nitrate as a carcinogen. Therefore, nitrate is not evaluated for carcinogenic effects for Waste Area Group 7.

The oral reference concentration for nitrate is 1.6E+00 mg/kg/day (EPA 2006). An uncertainty factor of 1 was employed because available data define no-observable-effect levels for the critical toxic effect in the most sensitive human subpopulation. Confidence in the reference concentration is high, based on evaluation of the database and studies included in the database.

6.3.1.5   Tetrachloroethylene. Liver toxicity in mice and weight gain in rats are critical effects of tetrachloroethylene (EPA 2006). Cardiac arrhythmia and renal injury also were observed in animal experiments. Exposure to tetrachloroethylene may cause dysfunction of the central nervous system, hepatic injury, and death. Signs and symptoms of exposure to tetrachloroethylene include malaise, dizziness, headaches, increased perspiration, fatigue, difficulty walking, and slowed mental ability (Sittig 1985).

Other effects of tetrachloroethylene exposure in humans range from loss of muscular coordination at low concentrations to unconsciousness and respiratory paralysis at high concentrations. Tetrachloroethylene is of moderate-to-low toxicity by the oral route. Ingestion may cause bleeding and diarrhea and irritate the gastrointestinal membranes. Chronic exposure to tetrachloroethylene most readily affects the central nervous system and liver (ATSDR 1990a).

Evaluating noncarcinogenic effects after ingestion of tetrachloroethylene uses a chronic reference concentration of 1.0E-02 mg/kg/day (EPA 2006). Tetrachloroethylene was not evaluated for noncarcinogenic effects by inhalation exposure because of insufficient data.

Evidence does not indicate that tetrachloroethylene is carcinogenic in humans; however, studies have shown that tetrachloroethylene can cause liver and kidney damage, liver and kidney cancers, and leukemia in animals. Because data are not provided in the Integrated Risk Information System database (EPA 2006), carcinogenic health effects were evaluated using an oral slope factor of 5.4E-04 and inhalation risk factor of 5.9E-03 obtained from an alternate source (OEHHA 2003).

Dermal absorption of tetrachloroethylene is relatively insignificant compared to the inhalation exposure route. However, two cases occurred where workers at a dry cleaning business reported blistering of the skin after accidental exposure to tetrachloroethylene (ATSDR 1990a).

6.3.1.6   *Trichloroethylene.* The EPA is reevaluating the evidence for classification of trichloroethylene as a carcinogen. Exposure and toxicity data currently are not available from the Integrated Risk Information System database (EPA 2006). Therefore, information presented in this section comes from existing toxicological profiles for trichloroethylene that incorporate data evaluated in an earlier EPA carcinogenic assessment.

Ingestion and inhalation are the principal routes of human exposure to trichloroethylene (ATSDR 1997). Human fatalities are associated with acute ingestion of trichloroethylene; however, no information is available for chronic oral exposures for humans (RAIS 2005). Primary critical effects resulting from oral exposure are increased liver and kidney weights and toxicity in mice and rats (RAIS 2005).

Critical effects produced by inhaling trichloroethylene include alterations to the central nervous, cardiovascular, and reproductive systems and to the liver and kidneys (RAIS 2005). Workers inhaling trichloroethylene produced symptoms relative to the central nervous system ranging from headaches and nausea to tremors and increased respiration (RAIS 2005). Inhalation exposure to trichloroethylene also produced liver and kidney toxicity in rats and dogs; and though not shown to be carcinogenic in rats, both male and female mice in one study developed liver cancers (NTP 1990).

Trichloroethylene was classified previously as a B2 carcinogen (RAIS 2005). Though data pertaining to carcinogenicity of trichloroethylene are being reevaluated (EPA 2006), the International Agency for Research on Cancer states that it is ". . .probably carcinogenic to humans." (ATSDR 2003).

A chronic reference concentration of 6.0E-01 mg/kg/day obtained from the Office of Environmental Health Hazard Assessment for the State of California (OEHHA 2003) was used to evaluate noncarcinogenic inhalation exposures to trichloroethylene. Data are not available to quantify noncarcinogenic effects of chronic oral exposure. An oral slope factor of 1.3E-02 and an inhalation unit risk of 2.0E-03 (OEHHA 2003) were used to evaluate carcinogenic effects of trichloroethylene.

6.3.2   Radionuclides

The EPA has classified all radionuclides as Group A carcinogens, based on the extensive weight of evidence provided by epidemiological studies of radiation-induced cancers in humans (EPA 1995). Target organs for radiation-induced cancers in humans include thyroid, breast, lungs, blood (bone marrow), stomach, liver, small and large intestines, brain, bone, esophagus, bladder, pancreas, lymphatic tissue, skin, pharynx, uterus, ovaries, and kidneys (EPA 1989). Any dose of radiation is assumed to produce adverse effects with no minimum threshold for radiation carcinogenesis.

The degree of radiotoxicity associated with a specific radioisotope depends on the type of emission (i.e., alpha, beta, or gamma), magnitude of energy, half-life, exposure pathway, and biological half-life. Slope factors developed by EPA reflect those characteristics. Shleien (1992) also grouped nuclides according to toxicity, based on the same characteristics, and rated them from one to four, describing very high, high, moderate, or low radiotoxicity. Table 6-4 lists the 25 radioisotopes evaluated for carcinogenic effects in the RI/BRA. The primary decay mode, toxicity classification, pathway-specific slope factors, and MCLs were tabulated for each nuclide. Pathway-specific slope factors were identified for ingestion, inhalation, and external exposure. The EPA recently updated their slope factor methodology to include individual ingestion slope factors for water, food, and soil ingestion. The RI/BRA incorporates this new methodology.

Descriptions of bodily effects for specific isotopes are available for only a few radionuclides. Other radionuclides are assessed in general terms according to types of decay emissions and their associated linear energy transfer values. Shleien (1992) describes the linear energy transfer value as ". . .a measure of the ability of biological material to absorb ionizing radiation; specifically, for charged particles traversing a medium, the energy lost per unit length of path as a result of those collisions with electrons in which the energy lost is less than a specified maximum value. . ."

The number of ionizations per unit distance generated by radiation as it traverses tissue is called the linear energy transfer of the radiation. Isotopes with low linear energy transfer typically are sparsely ionizing gamma or beta radiations and tend to travel farther into tissues than alpha particles. Target organs in humans, for cancers caused by low linear energy transfer, include the thyroid, breast, and blood (bone marrow) (NCRP 1980). Alpha-emitting isotopes usually exhibit high linear energy transfer, and effects tend to be more localized, reflecting the lesser degree of penetration associated with alpha particles. Consequently, alpha-emitting isotopes and low-energy beta particles generally are considered ingestion and inhalation hazards, but are not a significant external exposure concern. Conversely, gamma radiation can generate significant exposures by inhalation, ingestion, and external exposure. Target organs for gamma-induced cancers in humans include the thyroid, breast, lungs, blood (bone marrow), stomach, liver, small and large intestines, brain, bone, esophagus, bladder, pancreas, lymphatic tissue, skin, pharynx, uterus, ovaries, and kidneys. Breast cancer typically occurs 10 years after exposure (BEIR IV 1988), and thyroid cancer is a late consequence of ionizing radiation.

The most likely tissues to exhibit adverse health effects following intake of transuranic isotopes (i.e., elements of atomic number greater than 92) are the lungs, liver, bone (bone marrow), and lymph nodes and, to a lesser degree, thyroid gland, gonads, and kidneys (BEIR IV 1988). By far, the greatest emphasis was placed on the lungs and bone because these two tissues were the predominant sites of neoplasia in experimental animals.

The EPA slope factors reflect the considerations previously discussed. The following subsections provide additional descriptions for specific radioactive elements.

Table 6-4. Half-lives, slope factors, and other data used to estimate carcinogenic risk for radionuclide contaminants of potential concern and associated decay-chain members.

Radionuclide	Half-Life (years)	Primary Decay Mode[a]	Toxicity Group[b]	Water Ingestion Slope Factor[c] (pCi)^-1	Food Ingestion Slope Factor[c] (pCi)^-1	Soil Ingestion Slope Factor[c] (pCi)^-1	Inhalation Slope Factor[c] (pCi)^-1	External Exposure Slope Factor[c] (year/pCi/g)^-1	Maximum Contaminant Level[d] (pCi/L)
Ac-227+D	2.18E+01	B, A	1	4.86E-10	6.53E-10	1.16E-09	2.09E-07	1.47E-06	1.5E+01
Am-241	4.32E+02	A	1	1.04E-10	1.34E-10	2.17E-10	2.81E-08	2.76E-08	1.5E+01
Am-243+D[e]	7.38E+03	A	1	1.08E-10	1.42E-10	2.32E-10	2.70E-08	6.36E-7	1.5E+01
C-14	5.73E+03	B	3	1.55E-12	2.00E-12	2.79E-12	7.07E-12	7.83E-12	2.00E+03
Cl-36	3.01E+05	B[e]	2	3.30E-12	4.44E-12	7.66E-12	2.50E-11	1.74E-09	7.00E+02
Cs-137+D[f]	3.02E+01	B	3	3.04E-11	3.74E-11	4.33E-11	1.19E-11	2.55E-06	2.00E+02
I-129	1.57E+07	B	4	1.48E-10	3.22E-10	2.71E-10	6.07E-11	6.10E-09	1.00E+00
Nb-94	2.03E+04	B[e]	2	7.77E-12	1.11E-11	2.05E-11	3.77E-11	7.29E-06	1.07E+03
Np-237+D[f]	2.14E+06	A	1	6.74E-11	9.10E-11	1.62E-10	1.77E-08	7.97E-07	1.50E+01
Pa-231	3.28E+04	A	1	1.73E-10	2.26E-10	3.74E-10	4.55E-08	1.39E-07	1.50E+01
Pb-210+D[f]	2.23E+01	B	1	1.27E-09	3.44E-09	2.66E-09	1.39E-08	4.21E-09	NA
Pu-238	8.77E+01	SF, A	1	1.31E-10	1.69E-10	2.72E-10	3.36E-08	7.22E-11	1.50E+01
Pu-239	2.41E+04	A	1	1.35E-10	1.74E-10	2.76E-10	3.33E-08	2.00E-11	1.50E+01
Pu-240	6.54E+03	SF, A	1	1.35E-10	1.74E-10	2.77E-10	3.33E-08	6.98E-11	1.50E+01
Ra-226+D[f]	1.60E+03	A	1	3.86E-10	5.15E-10	7.30E-10	1.16E-08	8.49E-06	5.00E+00
Ra-228	5.75E+00	B	1	1.04E-09	1.43E-09	2.29E-09	5.23E-09	4.53E-06	5.00E+00
Sr-90+D	2.91E+01	B	2	7.40E-11	9.53E-11	1.44E-10	1.13E-10	1.96E-08	8.00E+00
Tc-99	2.13E+05	B	3	2.75E-12	4.00E-12	7.66E-12	1.41E-11	8.14E-11	9.00E+02
Th-228+D[f]	1.91E+00	A	1	3.00E-10	4.22E-10	8.09E-10	1.43E-07	7.76E-06	1.50E+01

Table 6-4. (continued).

Radionuclide	Half-Life (years)	Primary Decay Mode[a]	Toxicity Group[b]	Water Ingestion Slope Factor[c] (pCi)$^{-1}$	Food Ingestion Slope Factor[c] (pCi)$^{-1}$	Soil Ingestion Slope Factor[c] (pCi)$^{-1}$	Inhalation Slope Factor[c] (pCi)$^{-1}$	External Exposure Slope Factor[c] (year/pCi/g)$^{-1}$	Maximum Contaminant Level[d] (pCi/L)
Th-229+D[e,f]	7.34E+03	A	1	5.28E-10	7.16E-10	1.29E-09	2.25E-07	1.17E-06	1.50E+01
Th-230	7.70E+04	A	1	9.10E-11	1.19E-10	2.02E-10	2.85E-08	8.19E-10	1.50E+01
Th-232	1.41E+10	A	2	1.01E-10	1.33E-10	2.31E-10	4.33E-08	3.42E-10	1.50E+01
U-233	1.59E+05	A	1	7.18E-11	9.69E-11	1.60E-10	1.16E-08	9.82E-10	30 µg/L[g]
U-234	2.45E+05	A	1	7.07E-11	9.55E-11	1.58E-10	1.14E-08	2.52E-10	30 µg/L[g]
U-235+D[f]	7.08E+08	A	4	7.18E-11	9.76E-11	1.63E-10	1.01E-08	5.43E-07	30 µg/L[g]
U-236	2.34E+07	A	2	6.70E-11	9.03E-11	1.49E-10	1.05E-08	1.25E-10	30 µg/L[g]
U-238+D[f]	4.47E+09	SF, A	4	8.71E-11	1.21E-10	2.10E-10	9.35E-09	1.14E-07	30 µg/L[g]

a. Data are taken from Table 8.13 by Shleien (1992), except as noted (see Footnote e). Only primary emissions are listed. Many isotopes are characterized by multiple decay modes. Most emit gamma rays:

   A = alpha emission

   B = beta emission

   SF = spontaneous fission.

b. Values are taken from Table 11.1.1.1 by Shleien (1992):

   Group 1 = very high radiotoxicity

   Group 2 = high radiotoxicity

   Group 3 = moderate radiotoxicity

   Group 4 = low radiotoxicity.

c. Values are taken from the U.S. Environmental Protection Agency Health Effects Assessment Summary Tables (EPA 2001).

d. Values are taken from "National Primary Drinking Water Regulations" (40 CFR 141).

e. Data are taken from GE (1989).

f. "+D" indicates plus daughters, meaning that slope factors include the effects of daughter products.

g. Detected or simulated activities for each uranium itsotope are converted to mass and summed. The sum is then compared to the maximum contaminant level of 30 µg/L total uranium (EPA 2002).

6.3.2.1   *Actinium.* Data from early studies show the absorption of actinium through the gastrointestinal tract to be very low. As with other actinides, intravenously or intramuscularly injected actinium concentrates in the liver, bone, and to some extent, the kidneys (ICRP 1979).

6.3.2.2   *Americium.* Data from animal studies show absorption of americium through the gastrointestinal tract to be very low. Americium compounds are more rapidly cleared from the lungs than compounds of plutonium (ICRP 1979). After inhalation, Am-241 resides more in the skeleton than in the lungs (BEIR IV 1988), and approximately 30% of inhaled Am-241 resides in the liver. Inhalation has been shown to induce lung tumors in rats (BEIR IV 1988).

6.3.2.3   *Carbon.* Carbon is readily absorbed into the bloodstream through the gastrointestinal tract or the lungs and subsequently is deposited throughout all organs and tissues of the body. Data from the International Commission on Radiation Protection (ICRP 1975) suggest that the biological half-life of dietary carbon in the body is about 40 days; however, studies of autopsy samples of people exposed to C-14 from fallout indicate that bone collagen and bone mineral retain carbon with a biological half-life longer than 5 years (ICRP 1979).

6.3.2.4   *Cesium.* Cesium-137 rapidly absorbs into the bloodstream, regardless of the mode of exposure, and distributes throughout active body tissues. Metabolically, Cs-137 behaves as an analog of potassium. Distribution of cesium throughout the body and energetic beta and gamma radiation from the decay daughter (i.e., Ba-137m) result in essentially whole-body irradiation (Amdur, Doull, and Klassen 1991).

6.3.2.5   *Chlorine.* Little information describing the toxicological characteristics of radioactive chlorine is available. Beta emissions from chlorine pose an external hazard to skin and eyes. Chlorine-36 has a biological half-life of 10 days, and once in the body, Cl-36 is assumed to be distributed uniformly among all organs (ICRP 1980).

6.3.2.6   *Iodine.* Iodine is absorbed rapidly and almost completely through the gastrointestinal tract, mainly from the small intestine. Approximately 30% of iodine entering the blood is retained in the thyroid (ICRP 1979). Iodine eventually is lost from the thyroid gland in the form of organic iodine and is retained in the remaining organs and tissues within the body. The biological half-life of iodine within the body is approximately 120 days (ICRP 1979).

6.3.2.7   *Lead.* The fractional absorption of lead through the human gastrointestinal tract has an estimated range of 0.05 to 0.65 (ICRP 1979). When injected in the body, Pb-210 is deposited in bone, liver, and kidneys, but is tenaciously retained only by mineral bone (ICRP 1979).

6.3.2.8   *Neptunium.* Data from animal studies show the absorption of neptunium through the gastrointestinal tract to be very low. Experiments on rats indicate that neptunium is cleared from the lungs more rapidly than plutonium. Data on the distribution and retention of neptunium in rats indicate that the metabolic behavior of neptunium is similar to that of plutonium; however, in the skeleton, distribution of neptunium may more closely resemble calcium than plutonium (ICRP 1979).

6.3.2.9   *Niobium.* Data from the Reference Man Report (ICRP 1975) indicate that a large fraction of dietary niobium is absorbed through the gastrointestinal tract; however, other studies on some compounds of the element indicate that the fractional absorption is 0.01 or less in small animals (ICRP 1979). Inhaled niobium oxide is tenaciously retained in the lungs. Animal studies show a preferential retention of niobium in mineral bone, with a concentration 10 times the whole-body average; concentrations in the kidneys, spleen, and testes show concentrations three to five times the whole-body average.

6.3.2.10   Plutonium. After inhalation, plutonium may remain in the lungs, but can move to the bones and liver (BEIR V 1990). Plutonium generally stays in the body for a very long time and continues to expose the surrounding tissues to radiation (ATSDR 1990b), increasing the probability of carcinogenesis over time. Approximately 50% of plutonium entering the blood is retained in the bone and 30% in the liver, with retention times of 20 to 50 years (BEIR IV 1988). Inhalation can cause lung tumors in rats, and dermal absorption is limited (BEIR IV 1988).

Plutonium absorption through the gastrointestinal tract appears to be limited, but is increased with decreased iron and calcium levels (BEIR IV 1988). Data indicate a much higher gastrointestinal absorption for certain compounds of plutonium that are unlikely to be encountered in occupational exposures (e.g., hexavalent plutonium compounds, citrates, and other organic complexes). Absorption also is increased in the very young (ICRP 1979).

6.3.2.11   Protactinium. Data from early studies have shown absorption of protactinium through the gastrointestinal tract to be very low. In animal studies, protactinium deposits primarily in the skeleton, with the liver and kidneys as secondary sites of deposition (ICRP 1979). Protactinium deposited in the skeleton is retained there with a biological half-life greater than 100 days. Protactinium deposited in the liver or kidneys has a biphasic retention, with the two components having biological half-lives of about 10 and 60 days, respectively.

6.3.2.12   Radium. Radium, as a metabolic analog of calcium, is readily absorbed through the gastrointestinal tract or the lungs into the bloodstream and subsequently is deposited in the bones. Values for fractional absorption through the gastrointestinal tract were observed ranging from 0.15 to 0.21 (ICRP 1979). During the first few days after intake, radium concentrates heavily on bone surfaces and then gradually shifts its primary deposition site to bone volume. A large percentage of subjects exposed to high doses of radium have developed bone cancer (BEIR IV 1988).

6.3.2.13   Strontium. Strontium, as a metabolic analog of calcium, is readily absorbed into the bloodstream through the gastrointestinal tract or lungs and subsequently is deposited in the bones. Observations indicate that a single brief oral, intravenous, or inhalation intake generates a high incidence of tumors in bones and bone-related tissues (BEIR V 1990). Inhalation is the major risk. Data from animal studies indicate that exposure to strontium results in lung and possibly liver damage (Sittig 1985).

6.3.2.14   Technetium. Technetium is readily absorbed through the gastrointestinal tract or lungs into the bloodstream. Once in the body, technetium subsequently is deposited in the thyroid, gastrointestinal tract, and liver (ICRP 1979).

6.3.2.15   Thorium. Thorium is incorporated into the body mainly by inhalation. It is poorly absorbed through the gastrointestinal tract, and approximately 60% of the thorium body burden is present in the skeleton (BEIR IV 1988). In the body, thorium tends to stay where it is first deposited. When injected into humans as the drug Thorotrast, thorium deposited in the liver, spleen, bone marrow, and lymph nodes (BEIR IV 1988). Because of its deposition in the bone marrow where red blood cells form, thorium-induced anemia has been observed in conjunction with therapeutically administered Thorotrast. Liver cancers also were associated with Thorotrast therapy (BEIR IV 1988).

6.3.2.16   Uranium. Uranium and its compounds are highly toxic. Studies show that fractions of a uranium compound (e.g., 0.005 to 0.05) are likely to be absorbed into the blood through the gastrointestinal tract (ICRP 1979). Soluble uranium compounds such as UF_6, UO_2F_2, and $UO_2(NO_3)_2$ are absorbed rapidly through the lungs (ICRP 1979). Retention times for uranium in the body may range from 20 to 50 years (ICRP 1979). Major target organs for uranium toxicity are the respiratory system, blood, liver, lymphatic system, kidneys, skin, and bone marrow. Reports confirm that carcinogenicity is related

to dose and exposure time. Soluble compounds have been reported to cause lung and bone cancers and cancer of lymphatic tissues; whereas, insoluble compounds have been reported to cause cancer of lymphatic and blood-forming tissues (Sittig 1985).

6.4 Risk Characterization

Risk characterization involves estimating the magnitude of potential adverse human health effects from released contaminants of potential concern. Specifically, risk characterization combines the results of exposure and toxicity assessments to develop numerical estimates of the health risk. These estimates, with a given intake, are either comparisons of exposure levels with appropriate reference doses or estimates of the lifetime cancer risk.

Based on exposure scenarios and timeframes presented in Table 6-5, risks are assessed for carcinogenic and noncarcinogenic health effects using the generalized approach described in Section 6.4.1. During the simulated institutional control period (i.e., until the year 2110), the residential receptor is located at the INL Site boundary, and groundwater ingestion is the only complete exposure pathway. After the end of assumed institutional control, the residential receptor location moves to the SDA boundary, and all exposure pathways are computed. The occupational scenario is a worker on the SDA, and complete pathways are soil ingestion, inhalation, and external exposure. Sections 6.4.2 and 6.4.3 present results for 1,000- and 10,000-year simulation periods, respectively. Section 6.4.4 provides graphs illustrating simulated media concentrations, risk, and hazard indexes organized by simulation groups (established in Section 5) for both simulation periods.

Table 6-5. Risk scenario summary.

| Factor | Exposure Scenario | | | |
	Current Residential	Future Residential	Current Occupational	Future Occupational
Receptor	Resident	Resident	Worker	Worker
Location	Outside INL Site boundary	Outside SDA boundary	SDA	SDA
Exposure Pathway	Groundwater ingestion	All[a]	Soil ingestion, inhalation, and external exposure	Soil ingestion, inhalation, and external exposure
Timeframe (calendar years)	1952 through 2109	2110 through 3010 for all pathways except groundwater ingestion, which is computed until 12000	1952 through 2109	2110 through 3010
Results	See Table 6-7, Figure 6-2, Figures 6-4 through 6-16, and Section 6.4.3		See Table 6-6, Figure 6-3, and Section 6.4.2	

a. All pathways include soil ingestion, inhalation, external exposure, groundwater ingestion, and crop ingestion.

INL = Idaho National Laboratory
SDA = Subsurface Disposal Area

6.4.1 Generalized Approach

To quantify human health risks, contaminant intakes are calculated for each contaminant of potential concern for each applicable exposure route. As discussed in Section 6.2, these contaminant intakes are based on the modeled soil and groundwater concentrations listed in Table 6-1. Equations used to estimate risk for each pathway are discussed in the following subsections.

6.4.1.1   Carcinogenic Health Effects. Equations (6-12) through (6-14) are used to obtain numerical estimates (i.e., probability) of lifetime cancer risk:

$$\text{Risk} = \text{Intake} \times \text{SF} \tag{6-12}$$

where

      Risk   =   potential lifetime cancer risk (unitless)

      SF   =   slope factor, for chemicals $(mg/kg/day)^{-1}$ or radionuclides $(pCi)^{-1}$

      Intake =   chemical intake rate (mg/kg/day) or total radionuclide intake (pCi).

The linear low-dose equation shown in Equation (6-12) is valid at low risk levels (i.e., below the estimated risk of 1E−02). In accordance with the EPA Risk Assessment Guidance for Superfund (EPA 1989), risks that are greater than 1E−02 should be calculated using the one-hit equation. While no Waste Area Group 7 contaminants of potential concern fall into this category, Equation (6-13) describes the one-hit equation for completeness:

$$\text{Risk} = 1 - \exp^{(-\text{Intake} \times \text{SF})} \tag{6-13}$$

where

      Risk   =   potential lifetime cancer risk (unitless)

      SF   =   slope factor, for chemicals $(mg/kg/day)^{-1}$ or radionuclides $(pCi)^{-1}$

      Intake =   chemical intake rate (mg/kg/day) or total radionuclide intake (pCi).

To develop total risk for each contaminant, each pathway risk is summed as in Equation (6-14):

$$\text{Risk}_T = \Sigma \, \text{Risk}_i \tag{6-14}$$

where

      Risk_T =   total cancer risk for that contaminant

      Risk_i =   risk for the i pathway.

Similarly, the total risk for each contaminant is summed to estimate the potential cumulative cancer risk associated with the SDA.

6.4.1.2 Noncarcinogenic Effects. Health risks associated with exposure to individual noncarcinogenic compounds are evaluated by calculating hazard quotients. The quotient for health hazards is the ratio of intake to the reference concentration, as shown in Equation (6-15):

$$HQ = Intake/RfD \tag{6-15}$$

where

      HQ   =   noncarcinogenic hazard quotient (unitless)

      Intake   =   chemical intake rate (mg/kg/day)

      RfD   =   reference dose (mg/kg/day).

Hazard indexes are calculated by summing the hazard quotients for each chemical across all exposure routes. If the hazard index for any contaminant of potential concern exceeds 1.0, potential health effects from exposure to the contaminant of potential concern may be a concern. The contaminant-specific hazard index is calculated using Equation (6-16):

$$HI = \Sigma \, HQ_i \tag{6-16}$$

where

      HI   =   hazard index (unitless)

      HQ_i =   hazard quotient for each pathway (unitless).

Similarly, the hazard index estimated for each contaminant, as described above, can be summed to provide a cumulative hazard index for the entire SDA.

6.4.2 Estimates of the Potential Human Health Risk within 1,000 Years

This section presents baseline risk estimates for occupational and residential exposure scenarios within a 1,000-year simulation period. All exposure pathways were simulated for 1,000 years, from 2010 to 3010. Tables 6-6 and 6-7 summarize results for hypothetical occupational and residential scenarios, respectively. Comparison of results in the two tables shows that residential risks bound occupational risks (i.e., residential risks are greater than occupational risks). Figures 6-2 and 6-3 present total risk from all contaminants (i.e., both radionuclides and nonradionuclides) for occupational and residential exposure scenarios. The following subsections (1) summarize results for occupational and future residential scenarios (with detailed presentation for contaminants that exceed a cancer risk of 1E-05 or a hazard index of 1), (2) compare simulated groundwater concentrations to MCLs, and (3) illustrate risk and hazard index isopleths of cumulative groundwater risk.

Table 6-6. Summary of peak estimated risks and hazard indexes for the 1,000-year simulation period for hypothetical current and future occupational exposure scenarios.

Contaminant	Current Occupational Scenario (1952 to 2109)	Year of Peak	Future Occupational Scenario (2110 to 3010)	Year of Peak
		Risk		
Ac-227	3E-12	2109	4E-10	2305
Am-241	6E-06	2109	7E-04	2597
Am-243	6E-11	2109	2E-08	3010
C-14	6E-05	1963	3E-06	2110
Cl-36	4E-13	1987	2E-13	2152
Cs-137	7E-04	2025	4E-04	2110
I-129	6E-16	1967	2E-17	2195
Nb-94	2E-09	2109	3E-07	3010
Np-237	1E-08	2109	1E-06	2647
Pa-231	4E-13	2109	4E-11	2287
Pb-210	1E-08	2109	3E-06	3010
Pu-238	5E-09	2109	3E-07	2265
Pu-239	5E-07	2109	7E-04	3010
Pu-240	1E-07	2109	2E-04	3010
Ra-226	7E-07	2109	1E-04	3010
Ra-228	3E-08	2109	6E-06	3010
Sr-90	3E-05	2013	1E-05	2110
Tc-99	1E-09	1984	3E-11	2110
Th-228	6E-08	2109	1E-05	3010
Th-229	4E-11	2109	2E-08	3010
Th-230	4E-12	2109	1E-09	3010
Th-232	2E-10	2109	4E-08	3010
U-233	9E-12	2109	4E-10	2288
U-234	2E-10	2109	1E-08	2290
U-235	8E-10	2109	4E-08	2288
U-236	5E-12	2109	3E-10	2333
U-238	6E-09	2109	3E-07	2287
Carbon tetrachloride	1E-03	1967	9E-06	2110
1,4-Dioxane	1E-16	1964	6E-38	2110
Methylene chloride	6E-07	1961	1E-08	2110
Tetrachloroethylene	7E-06	1961	1E-07	2110
Trichloroethylene	8E-02[a]	1967	5E-04[a]	2110

Table 6-6. (continued).

Contaminant	Current Occupational Scenario (1952 to 2109)	Year of Peak	Future Occupational Scenario (2110 to 3010)	Year of Peak
		Hazard Index		
Carbon tetrachloride	1E-08	1967	4E-30	2110
Methylene chloride	4E-12	1959	1E-31	2110
Nitrate	4E-08	1965	7E-23	2110
Tetrachloroethylene	3E-09	1974	3E-11	2145

a. The risk values for trichloroethylene are scaled from carbon tetrachloride. Actual risk values will be computed for the feasibility study.

Indicates risk estimate greater than 1E-06 for the current occupational scenario or greater than 1E-05 for the future occupational scenario. No hazard index is highlighted because none are greater than 1.

Table 6-7. Summary of estimated risks and hazard indexes for the 1,000-year simulation period for a hypothetical future residential exposure scenario.

Contaminant	Simulation Group	Peak	Year of Peak	Primary Exposure Pathways
			Risk	
Ac-227	2	5E-07	3010	Groundwater ingestion
Am-241	1	3E-03	2594	External exposure, soil ingestion, inhalation, and crop ingestion
Am-243	2	1E-07	3010	External exposure
C-14	8	1E-05	2110	Groundwater ingestion and inhalation of volatiles (at the surface)
Cl-36	6	2E-06	2384	Groundwater ingestion and crop ingestion
Cs-137	9	2E-03	2110	External exposure and crop ingestion
I-129	6	4E-05	2110	Groundwater ingestion
Nb-94	9	2E-06	3010	External exposure
Np-237	1	7E-06	2647	External exposure
Pa-231	2	3E-07	3010	Groundwater ingestion
Pb-210	4 and 5	3E-05	3010	Crop ingestion
Pu-238	4	1E-06	2262	Soil ingestion, crop ingestion, and inhalation
Pu-239	2	3E-03	3010	Soil ingestion, crop ingestion, and inhalation
Pu-240	3	6E-04	3010	Soil ingestion, crop ingestion, and inhalation
Ra-226	4 and 5	7E-04	3010	External exposure and crop ingestion
Ra-228	3	3E-05	3010	External exposure, external exposure, and soil ingestion
Sr-90	9	1E-03	2110	Crop ingestion
Tc-99	6	3E-04	2110	Groundwater ingestion and crop ingestion (crops irrigated with contaminated groundwater)

Table 6-7. (continued).

Contaminant	Simulation Group	Peak	Year of Peak	Primary Exposure Pathways
Th-228	9	5E-05	3010	External exposure
Th-229	1	4E-07	3010	Groundwater ingestion
Th-230	4 and 5	1E-08	3010	Soil ingestion, crop ingestion, and inhalation
Th-232	3	3E-07	3010	Crop ingestion
U-233	1	4E-06	3010	Groundwater ingestion
U-234	4 and 5	6E-07	3010	Groundwater ingestion
U-235	2	2E-07	2286	External exposure
U-236	3	9E-07	3010	Groundwater ingestion
U-238	5	1E-06	2285	External exposure
Carbon tetrachloride	11	5E-04	2110	Inhalation of volatiles (at the surface) and groundwater ingestion
1,4-Dioxane	11	2E-05	2110	Groundwater ingestion
Methylene chloride	11	5E-06	2244	Groundwater ingestion
Tetrachloroethylene	11	7E-07	2110	Groundwater ingestion
Trichloroethylene	11	9E-04[a]	2110	Inhalation of volatiles
Hazard Index				
Carbon tetrachloride	11	1E+01	2116	Inhalation of volatiles (at the surface) and groundwater ingestion
Methylene chloride	11	3E-02	2244	Groundwater ingestion
Nitrate	10	1E+00	2110	Groundwater ingestion
Tetrachloroethylene	11	3E-01	2133	Groundwater ingestion

a. Risk scaled from carbon tetrachloride risk. Actual risk will be computed for the feasibility study.

Indicates risk estimate greater than or equal to 1E-05 or hazard index greater than or equal to 1.
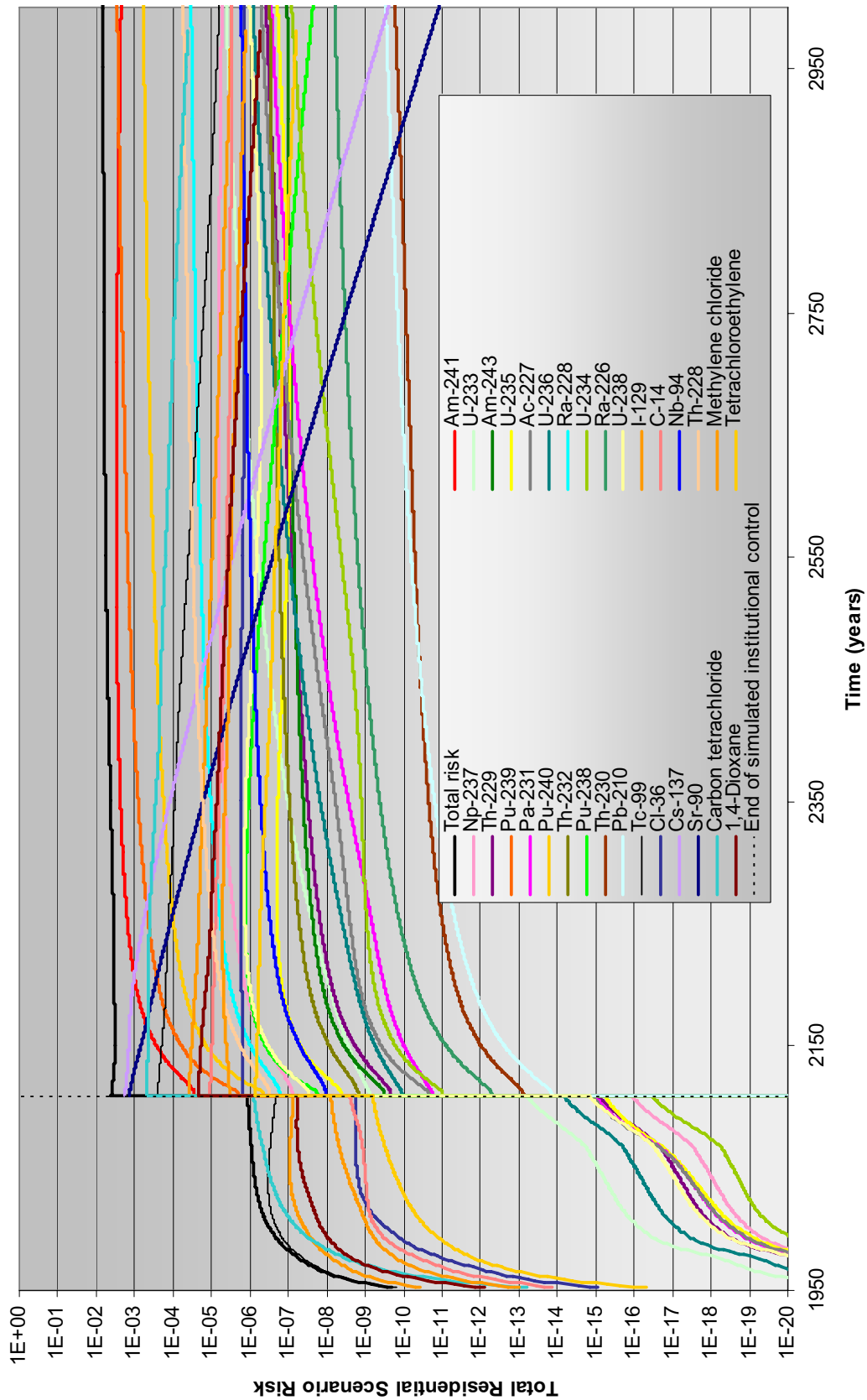
Figure 6-2. Total carcinogenic risks over all pathways for chemical and radiological contaminants of potential concern for the hypothetical current and future residential exposure scenarios.
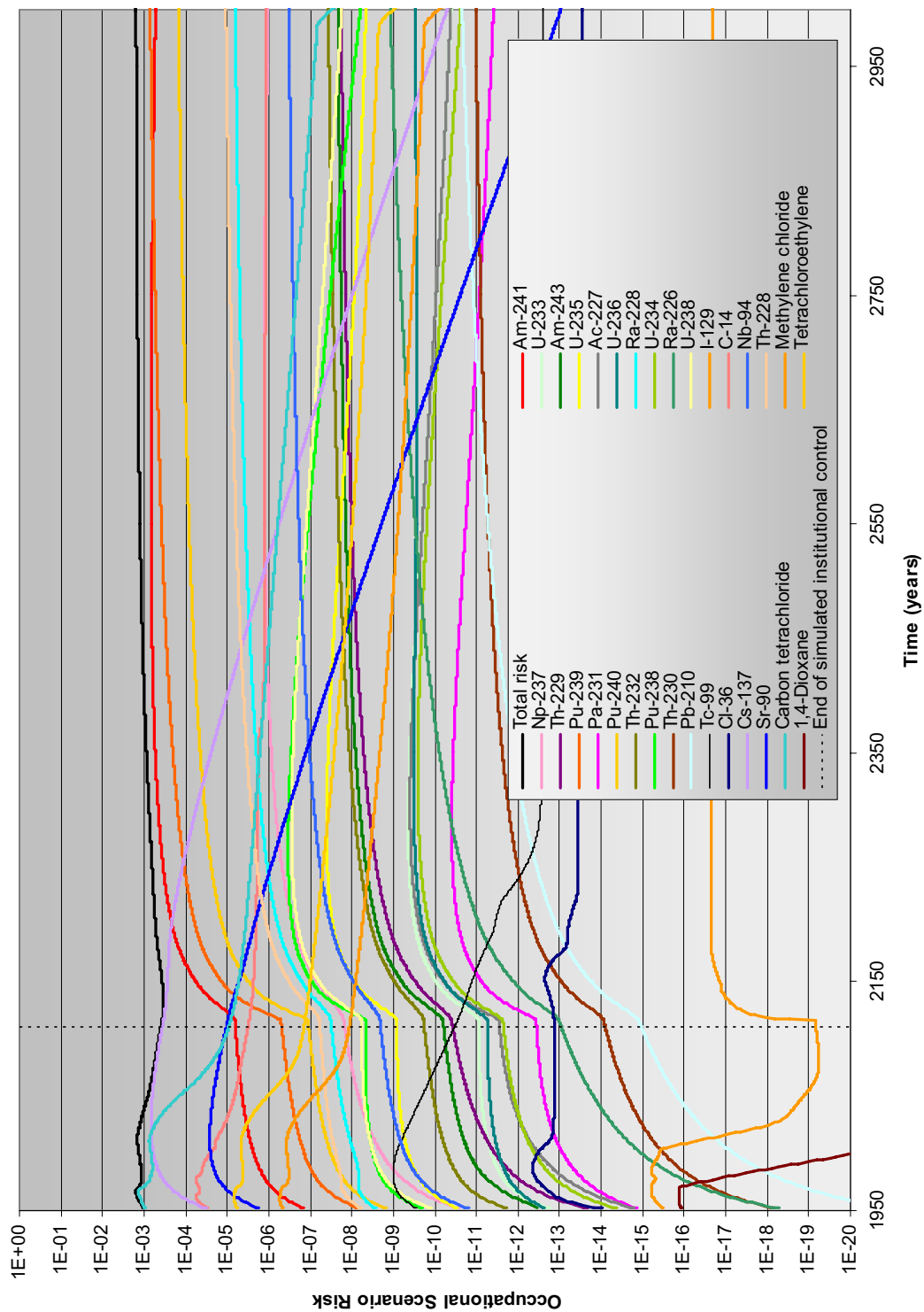
Figure 6-3. Total carcinogenic risks over all pathways for chemical and radiological contaminants of potential concern for hypothetical current and future occupational exposure scenarios.

6.4.2.1   Occupational Scenarios. Table 6-6 lists risks and hazard indexes for the occupational exposure scenario. Health impacts are computed for 1,000 years, in accordance with the Second Addendum (Holdren and Broomfield 2004), because current occupational scenario risk exceeds 1E-06. Peak risks and hazard indexes are provided for two periods. The first period is through the simulated 100-year institutional control period ending in the year 2110, and the second period is the balance of the 1,000-year simulation period ending in the year 3010. Because this RI/BRA evaluates risk in the absence of remedial action, current and future occupational scenario risk estimates do not account for ongoing controls that prevent these risks from materializing. The one exception is for groundwater ingestion, which is precluded by management controls for occupational scenarios. Americium-241, C-14, Sr-90, and carbon tetrachloride have risks greater than 1E-06 during institutional control; therefore, 1,000-year occupational risks are computed.

Figure 6-3 shows total carcinogenic risk for the hypothetical future occupational scenario. In the period of institutional control, carbon tetrachloride dominates the risk through inhalation. After institutional control, Cs-137 and Sr-90 drive the near-term risks, and Am-241, Pu-239, and Pu-240 drive long-term occupational scenario risks. For Am-241, the peak risk is from external exposure and inhalation of fugitive dust. For both C-14 and carbon tetrachloride, the peak risk is from volatile inhalation. The Sr-90 risk is primarily from external exposure. Sections 6.4.4.1 through 6.4.4.10 provide plots of occupational risk for each group simulated.

6.4.2.2   Residential Scenarios—Table 6-7 lists maximum risk and hazard indexes for each contaminant for the 1,000-year simulation period for hypothetical future residential exposures. Also listed are years in which peak risks occur and primary exposure pathways contributing to total risk. The peak risk or hazard index for groundwater ingestion is the maximum anywhere in the aquifer outside the SDA. These peak risks cannot be summed to assess cumulative risk because times and locations of the peaks vary by contaminant (i.e., a receptor at one point in time with a well in one location would not accrue the maximum groundwater risk for all contaminants).

Figures 6-4 through 6-19 (presented in alphabetic order, first by radionuclides then by nonradionuclides) illustrate residential scenario risk over time for contaminants of potential concern with risk estimates greater than 1E-05 or a hazard index greater than 1 in the 1,000-year simulation period. The end of the simulated institutional control period in the year 2110 is indicated with a vertical dotted line. All complete pathways are simulated. Because of institutional controls, the receptor location is the INL Site boundary for the first 100 years, and groundwater ingestion is the only complete exposure pathway. After the 100-year period of institutional control, the receptor location moves to the SDA boundary, and graphs show all pathways, including groundwater ingestion. The risk plots show a marked increase at the end of institutional control because of additional pathways and the change in receptor location. In many cases, groundwater ingestion risk at the INL Site boundary is so small that it does not appear on the graph. In previous assessments (e.g., IRA and ABRA), occupational risk was shown for the institutional control period, and the residential risk was presented after institutional control.

As discussed in Section 5.5, more conservative biotic uptake modeling was applied in the RI/BRA compared to the ABRA. Consequently, surface exposure pathway risk estimates are correspondingly greater. Most risks greater than 1E-04 are attributable to surface exposure pathways (e.g., external exposure, crop ingestion, and soil ingestion). Only Tc-99 and carbon tetrachloride risk estimates have significant groundwater pathway components. Carbon tetrachloride and nitrate, the only contaminants with a total hazard index of 1 or greater, are illustrated in Figures 6-17 and 6-19, respectively.
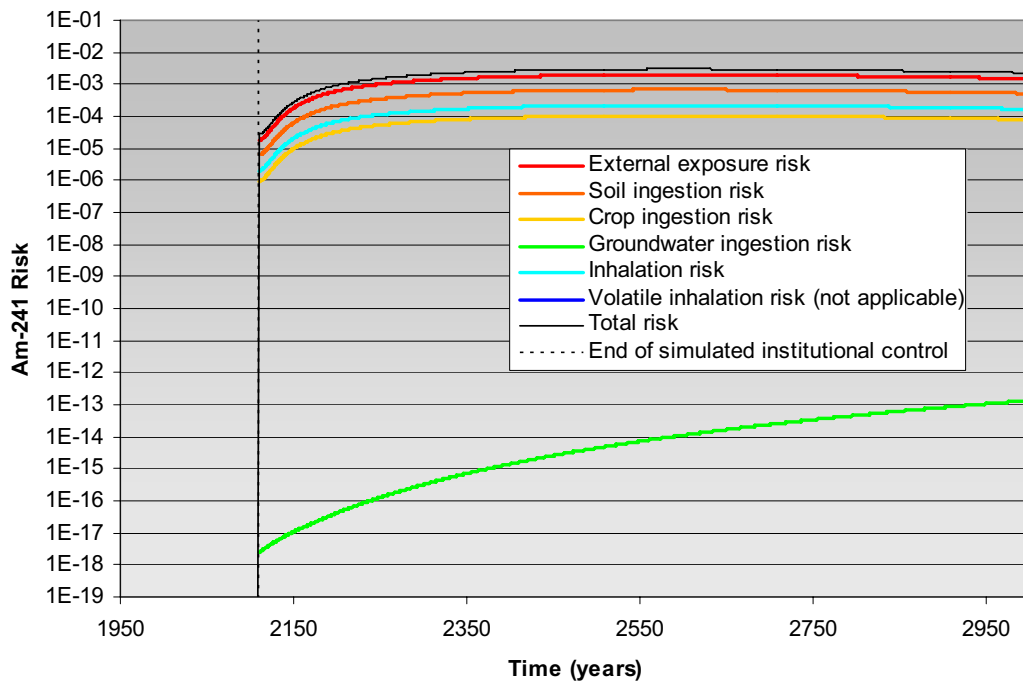
Figure 6-4. Americium-241 carcinogenic risks for hypothetical future residential scenario exposure pathways.
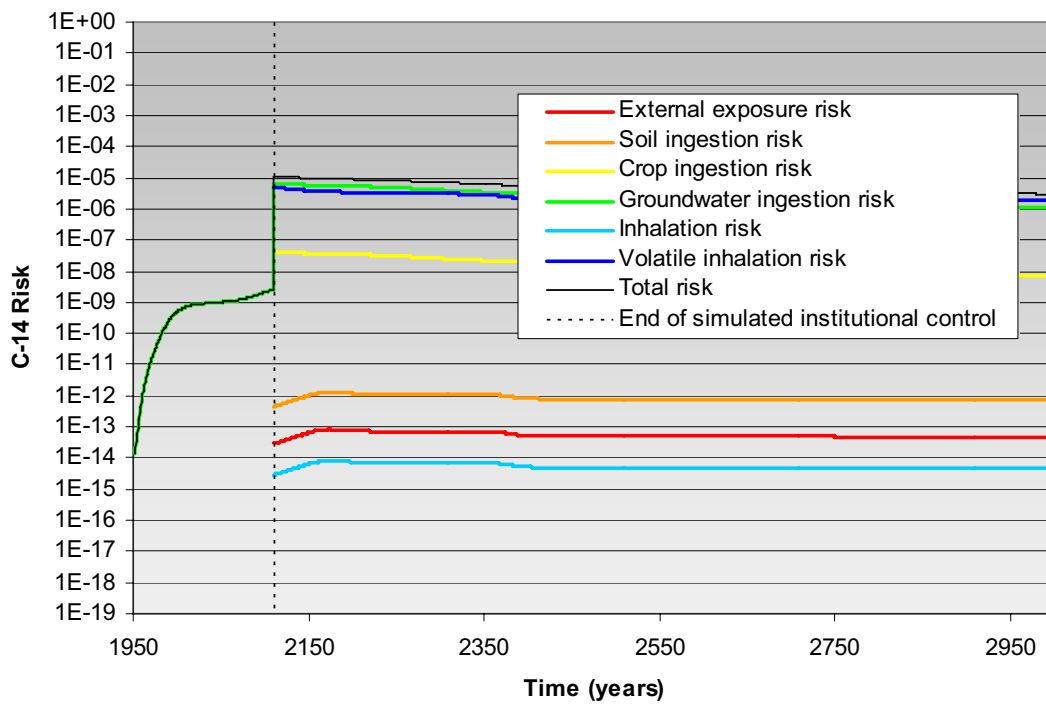
Figure 6-5. Carbon-14 carcinogenic risks for hypothetical future residential scenario exposure pathways.
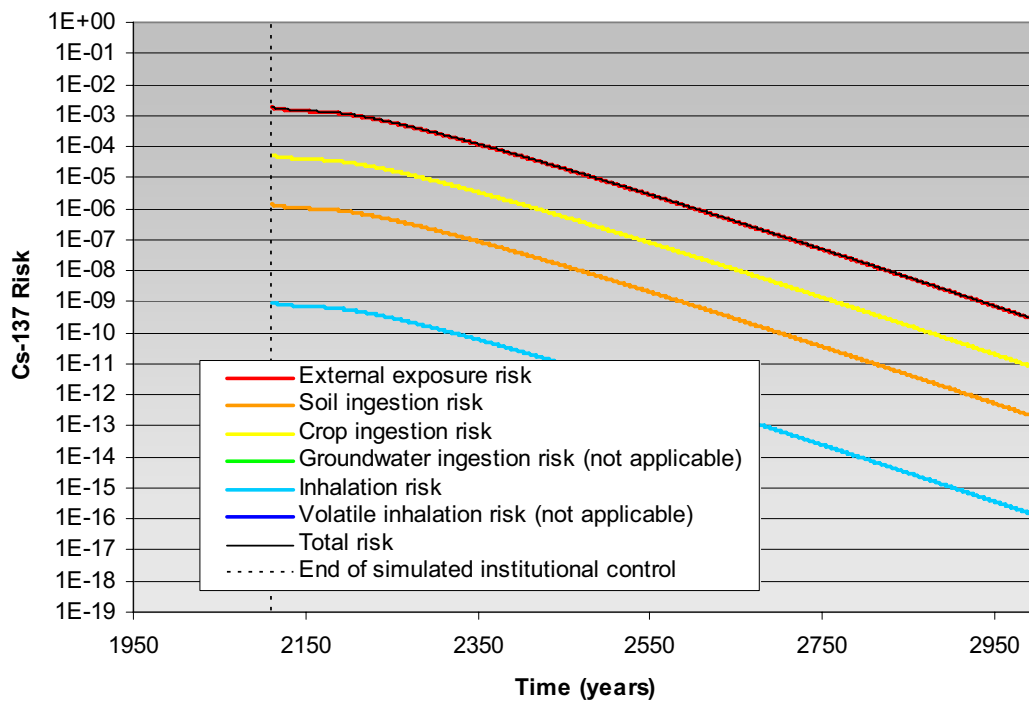
Figure 6-6. Cesium-137 carcinogenic risks for hypothetical future residential scenario exposure pathways.
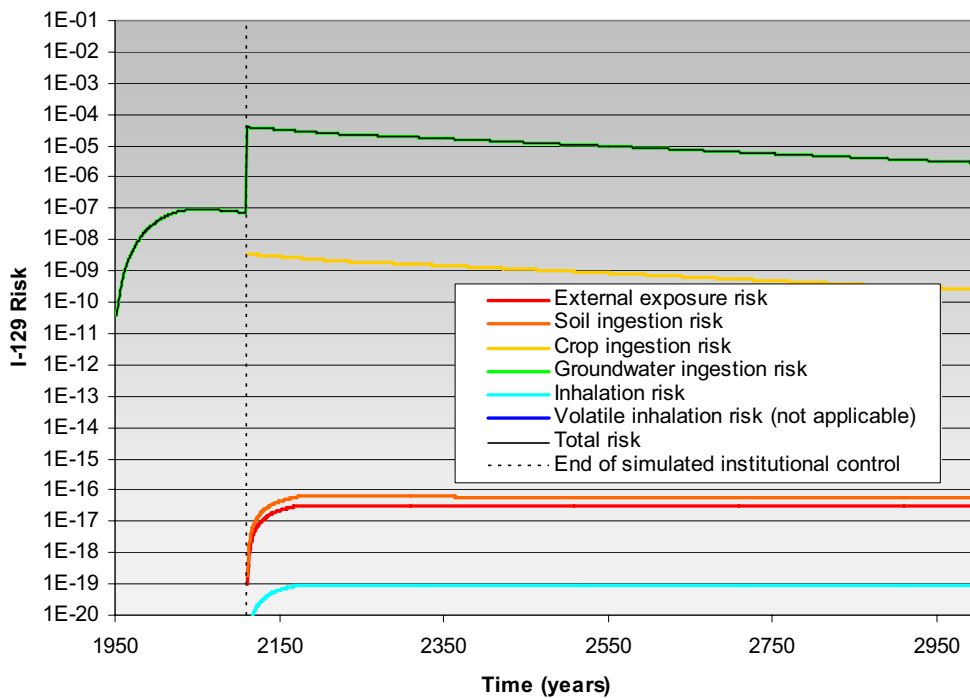
Figure 6-7. Iodine-129 carcinogenic risks for hypothetical future residential scenario exposure pathways.

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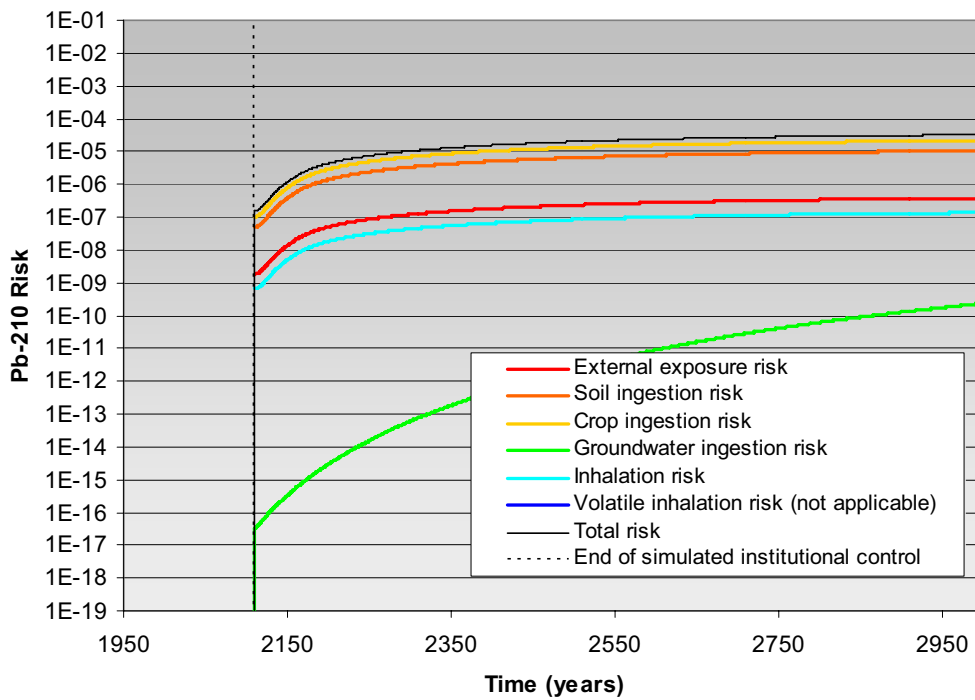
Figure 6-8. Lead-210 carcinogenic risks for hypothetical future residential scenario exposure pathways.
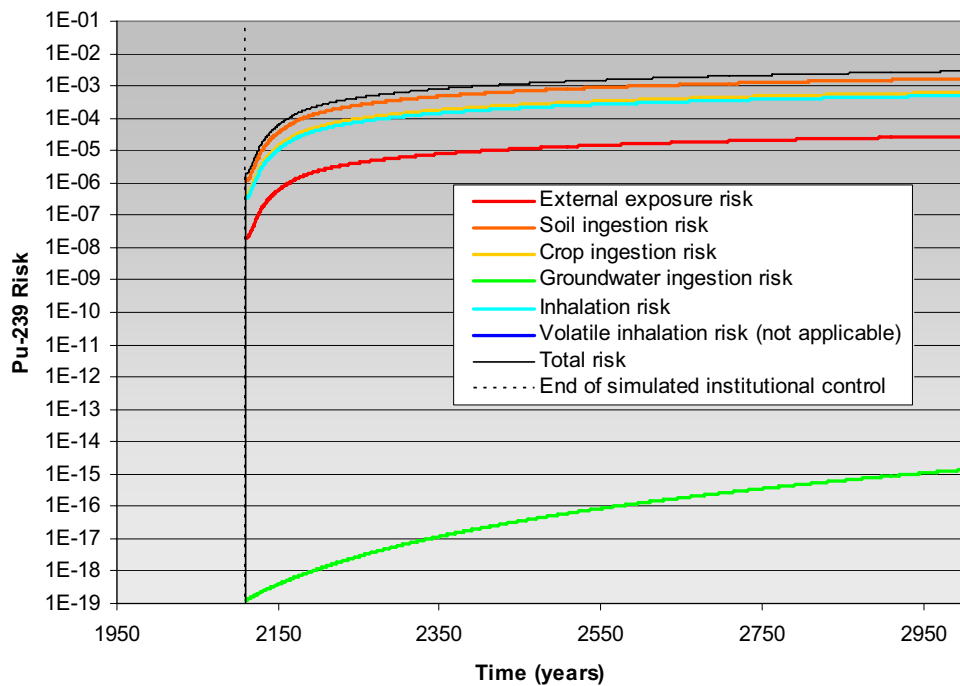
Figure 6-9. Plutonium-239 carcinogenic risks for hypothetical future residential scenario exposure pathways.
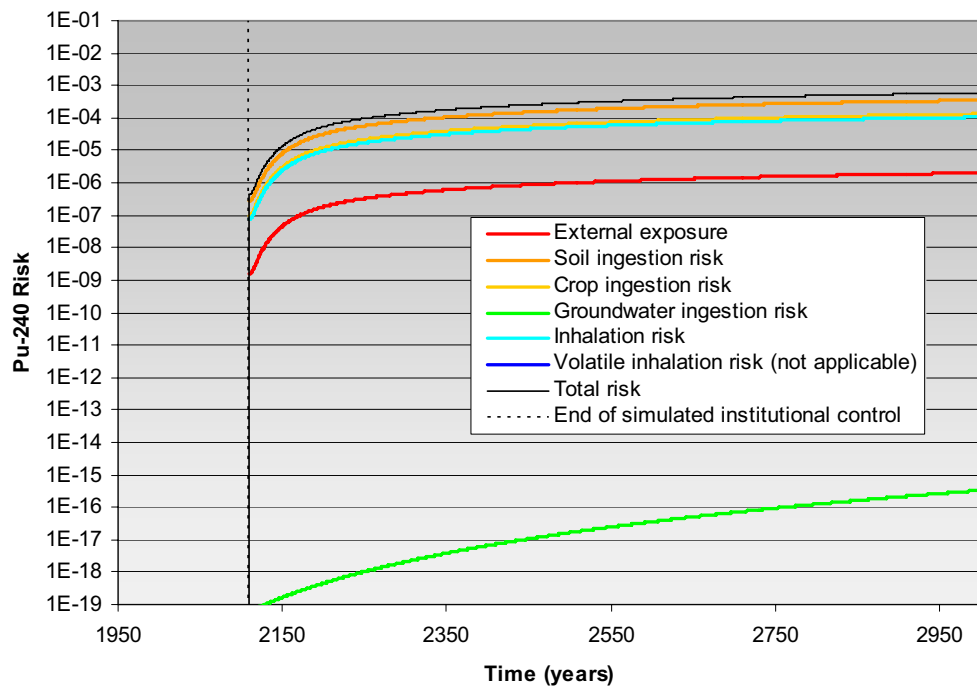
Figure 6-10. Plutonium-240 carcinogenic risks for hypothetical future residential scenario exposure pathways.
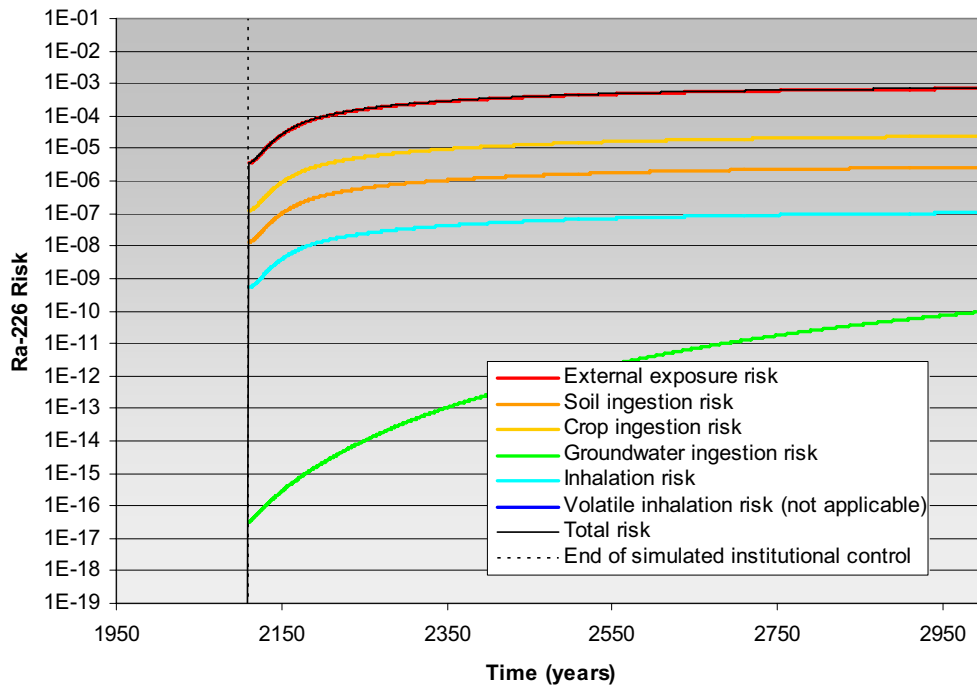
Figure 6-11. Radium-226 carcinogenic risks for hypothetical future residential scenario exposure pathways.
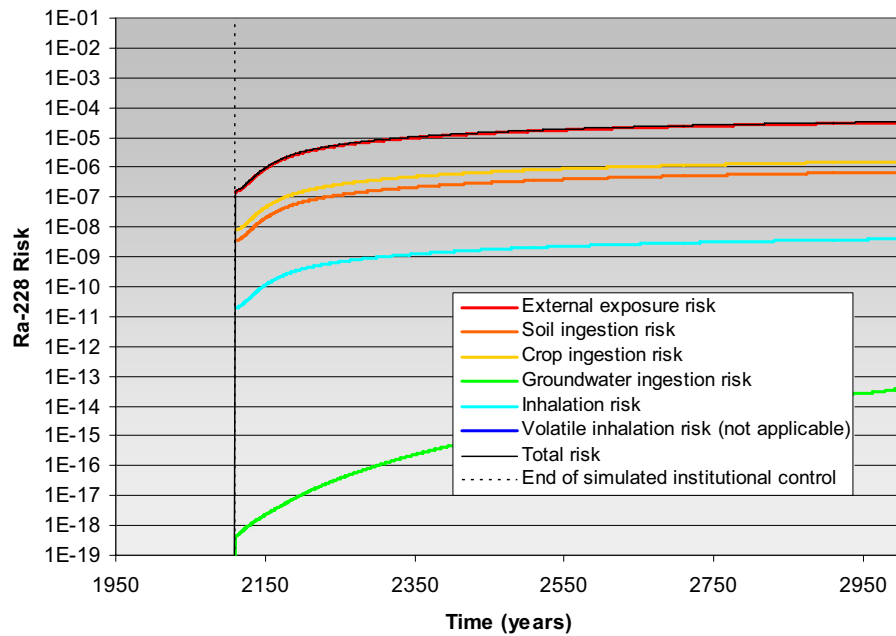
Figure 6-12. Radium-228 carcinogenic risks for hypothetical future residential scenario exposure pathways.
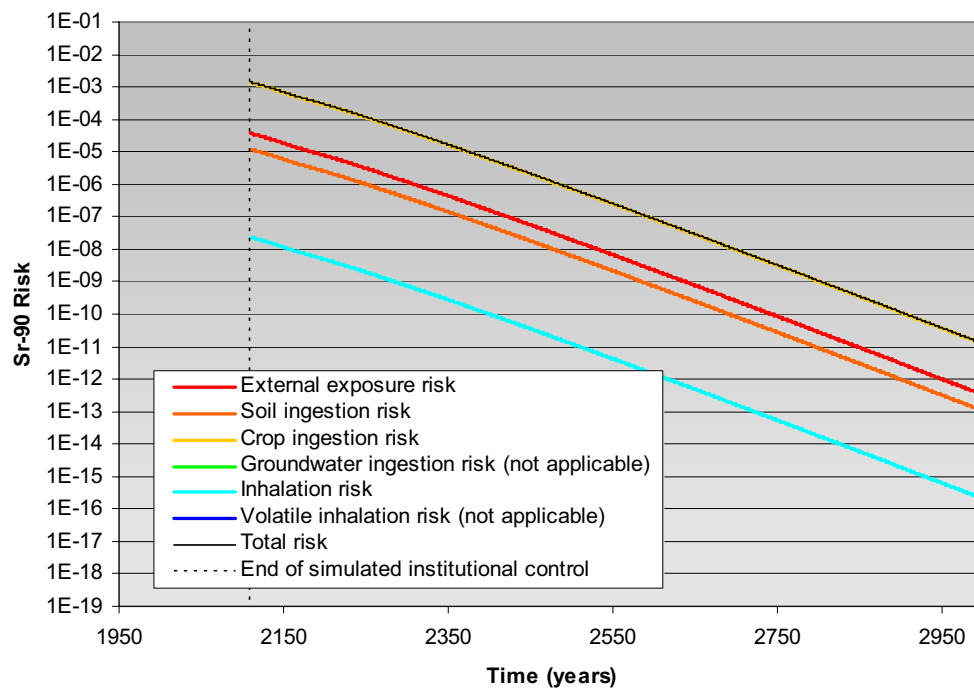
Figure 6-13. Strontium-90 carcinogenic risks for hypothetical future residential scenario exposure pathways.
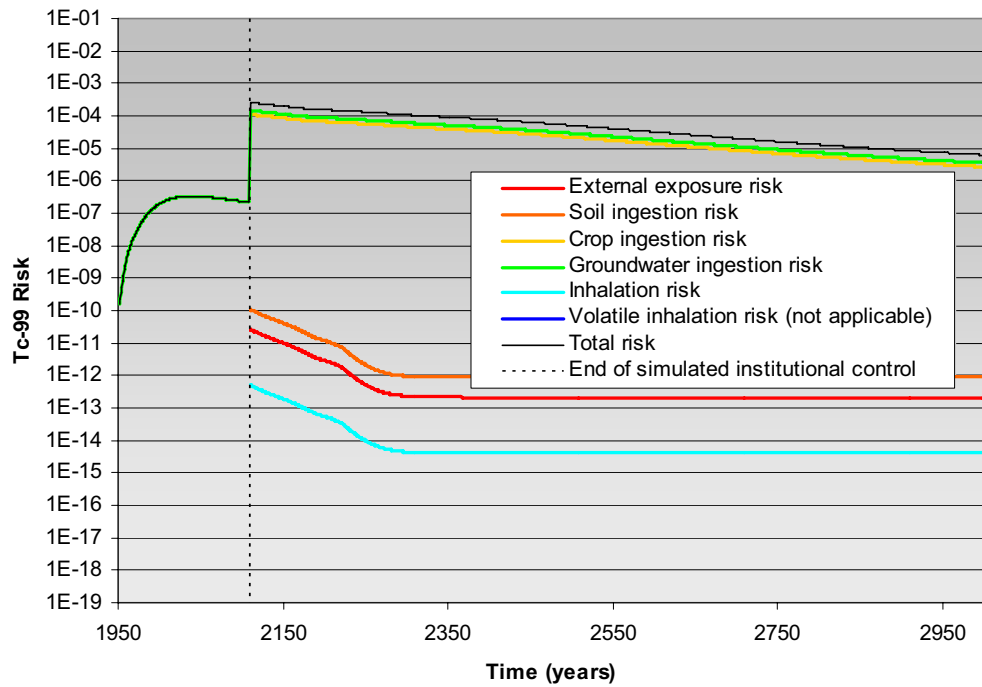
Figure 6-14. Technetium-99 carcinogenic risks for hypothetical future residential scenario exposure pathways.
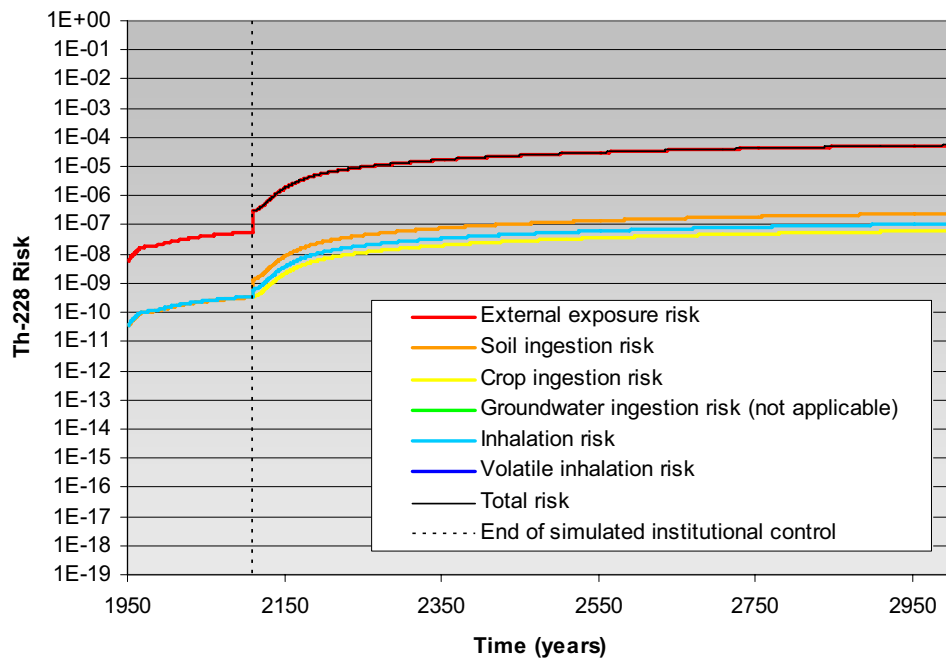
Figure 6-15. Thorium-228 carcinogenic risks for hypothetical future residential scenario exposure pathways.
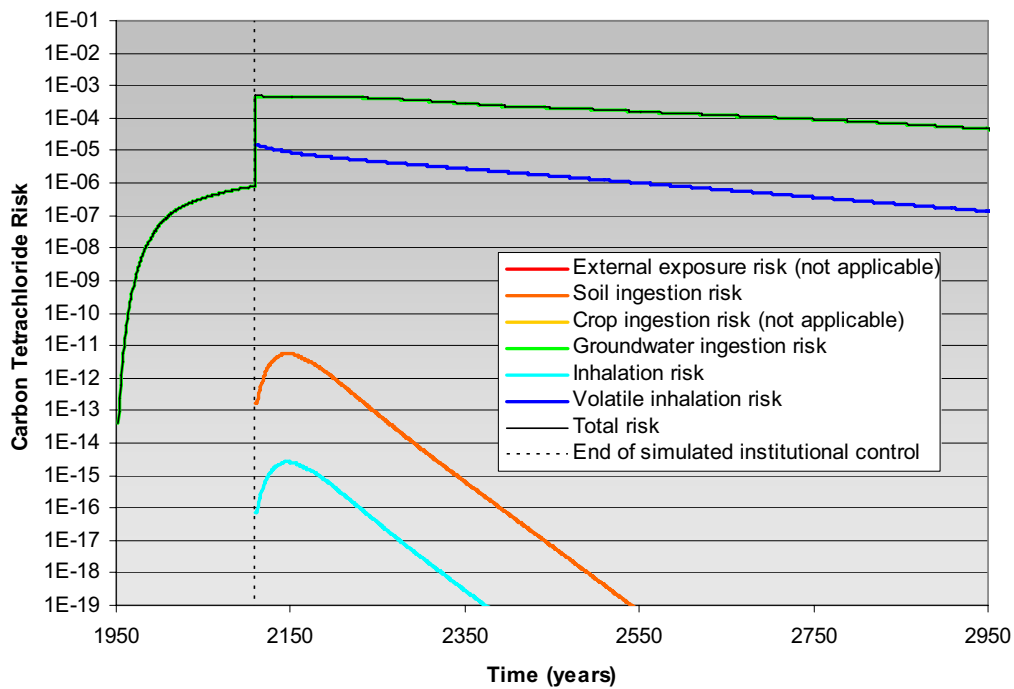
Figure 6-16. Carbon tetrachloride carcinogenic risks for hypothetical future residential scenario exposure pathways.
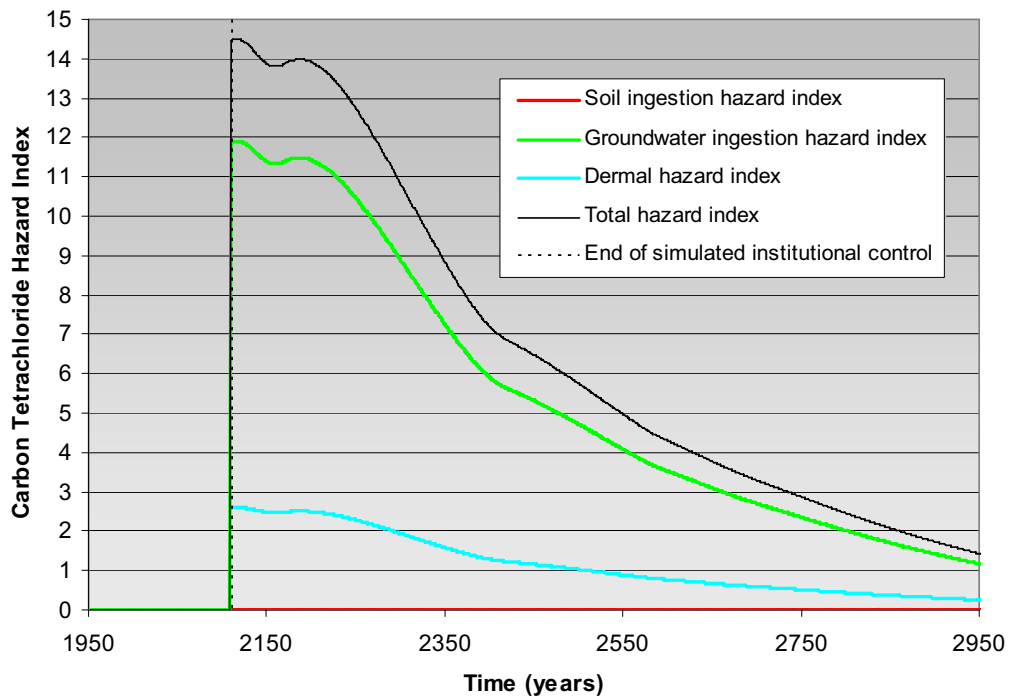
Figure 6-17. Carbon tetrachloride hazard index for hypothetical future residential scenario exposure pathways.
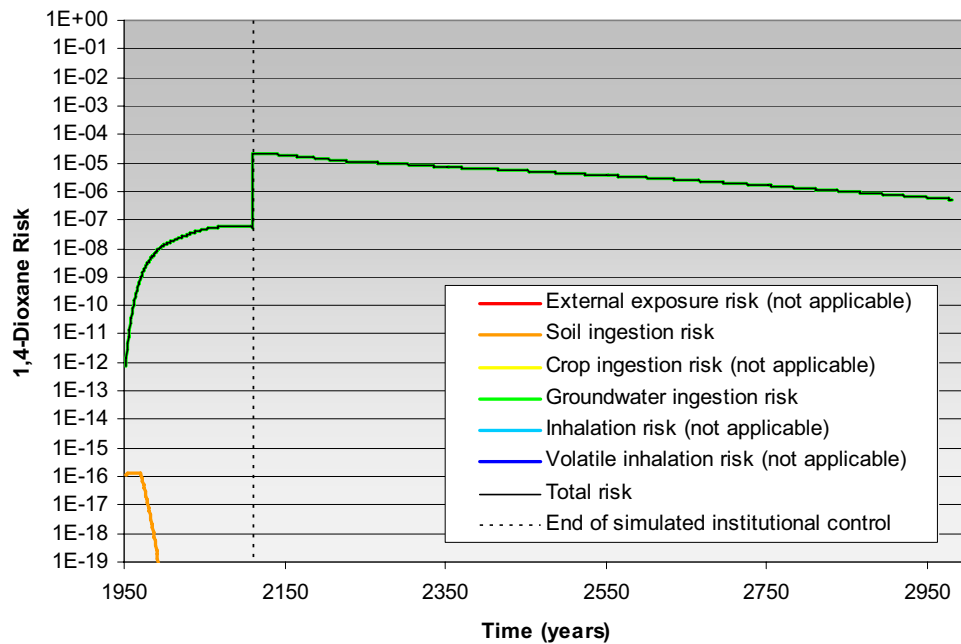
Figure 6-18. 1,4-Dioxane carcinogenic risks for hypothetical future residential scenario exposure pathways.
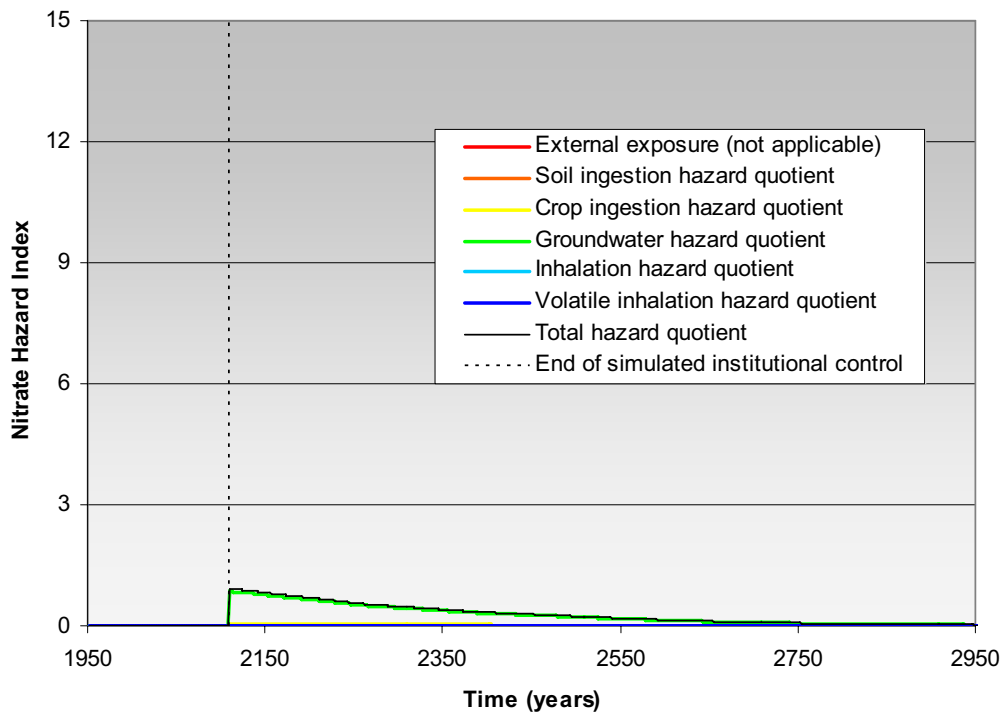
Figure 6-19. Nitrate hazard index for hypothetical future residential scenario exposure pathways.

As illustrated in Figure 6-2, the total maximum carcinogenic risk from radionuclides within the 1,000-year simulation period is 7E-03 for the hypothetical future residential scenario. The total estimated risk is dominated by soil exposure risks attributable to biotic transport of contaminants to the surface. Initially, post-institutional-control residential risk is dominated by Sr-90 and Cs-137; in later periods, Am-241 and Pu-239 drive the risks. Groundwater concentrations are still increasing at the end of the 1,000-year simulation period for some radionuclides. Results for 10,000-year groundwater ingestion are presented in Section 6.4.3.

The following summary describes contaminants with risk greater than 1E-05 or a hazard index greater than 1 within 1,000 years for the future residential scenario. The list is ordered alphabetically by radionuclides and nonradionuclides.

- **Am-241**—Risk from Am-241 is dominated by external exposure and soil ingestion pathways, as shown in Figure 6-4. Inhalation and crop ingestion also pose risk greater than 1E-05. The risk peaks at 3E-03 near the year 2600 and gradually diminishes through radioactive decay. Because of the low mobility of Am-241, groundwater ingestion risk is low, especially before the end of institutional control.

- **C-14**—Current modeling accounts for C-14 partitioning into the vapor phase (see Section 5.5). Carbon-14 vapor is more mobile, but some of the mass released will be released to the atmosphere and will not affect groundwater. As shown in Figure 6-5, peak risk occurs at the end of the institutional control period and is primarily from groundwater ingestion and inhalation of volatiles at the surface. Though individual risk for these two primary pathways is less than 1E-05 each, they combine for a cumulative peak risk of 1E-05.

- **Cs-137**—Cs-137 risk peaks at 2E-03 at the end of institutional control. Because of its relatively short half-life of 30 years, the risk decreases from that year forward. Cesium-137 was not simulated for the groundwater ingestion pathway because its short half-life and low mobility preclude it from posing a groundwater ingestion risk. As illustrated in Figure 6-6, risk comes from direct exposure to ionizing radiation and crop ingestion.

- **I-129**—I-129 risk peaks at the end of institutional control, as shown in Figure 6-7. Peak risk is 4E-05 and is primarily from groundwater ingestion. As with Tc-99, conservative assumptions made for the source-release modeling cause predicted I-129 concentrations to be far greater than measured concentrations.

- **Pb-210**—Peak risk for Pb-210 is 3E-05 and, as shown in Figure 6-8, occurs at the end of the 1,000-year simulation period. The peak risk is from the crop ingestion pathway. The majority of Pb-210 is generated from decay of U-238 and Pu-238. Because of the time to generate inventory of Pb-210 and its low mobility, the risk peak is at the end of the 1,000-year simulation period.

- **Pu-239**—Risk peaks at 3E-03 at the end of the 1,000-year simulation period. Figure 6-9 shows that primary pathways are soil ingestion, crop ingestion, and inhalation. Because Pu-239 has a longer half-life and a lower mobility than Am-241, its risk does not start to decline at the end of the 1000-year simulation period. Negligible impact to the aquifer is predicted from Pu-239.

- **Pu-240**—Peak risk for Pu-240 is 6E-04 and is also at the end of the 1,000-year simulation period. As shown in Figure 6-10, the primary pathways are soil ingestion, crop ingestion, and inhalation. Again, low mobility and long half-life mean that surface soil concentrations do not start to decline by the end of the 1,000-year simulation period, but impact to the aquifer is negligible.

- **Ra-226**—Ra-226 risk peaks at 7E-04 at the end of the 1,000-year simulation period, as shown in Figure 6-11. External exposure and crop ingestion are the primary exposure pathways. Because the majority of Ra-226 is produced through ingrowth from the decay of Pu-238 and U-238, it tends to peak later than Am-241 even though they have about the same mobility.

- **Ra-228**—Ra-228 risk peaks at 3E-05 at the end of the 1,000-year simulation period. Figure 6-12 shows that external exposure is the primary pathway. Radium-228 is produced through decay of Pu-240. Because Ra-228 has a short half-life (5.75 years), its risk closely parallels the risk curve of the parent (i.e., Pu-240).

- **Sr-90**—Crop ingestion dominates Sr-90 risk, as shown in Figure 6-13. External exposure and soil ingestion also pose risk greater than 1E-05. Risk peaks at 1E-03, immediately after the simulated 100-year institutional control period, then drops rapidly because of radioactive decay. Groundwater ingestion risk was not computed for Sr-90 because of its short half-life and low mobility.

- **Tc-99**—Tc-99 risk peaks at the end of the 100-year institutional control period. Figure 6-14 shows that peak risk is 3E-04, which is primarily from groundwater ingestion and crop ingestion from using groundwater to irrigate crops. The marked increase in groundwater ingestion risk at the end of institutional control is caused by the change in receptor location from the INL Site boundary to the SDA boundary. As discussed in Section 5, concentrations of Tc-99 predicted by the model are much greater than detected concentrations. The model shows that most of the source has already been released; however, monitoring data do not corroborate that conclusion (see Section 5.2.5).

- **Th-228**—Th-228 risk peaks at 5E-05 at the end of the 1,000-year simulation period and is primarily from direct exposure to ionizing radiation (see Figure 6-15). Because Th-228 has a short half-life, the risk comes from ingrowth from the decay of Ra-228.

- **Carbon tetrachloride**—Risk from carbon tetrachloride peaks at 5E-04 at the end of institutional control. Carcinogenic risk attributable to carbon tetrachloride is dominated by inhalation of volatiles at the surface and groundwater ingestion (see Figure 6-16). Carbon tetrachloride dominates the total hazard index with a hazard index of 1E+01. Figure 6-17 illustrates the carbon tetrachloride hazard index, which is attributable primarily to groundwater ingestion. The marked increase in the groundwater ingestion risk and hazard index is caused by the change in receptor location from the INL Site boundary to the SDA boundary.

- **1,4-Dioxane**—Risk from 1,4-dioxane is from groundwater ingestion. The peak risk of 2E-05 occurs at the end of institutional control (see Figure 6-18).

- **Nitrate**—The hazard index from nitrate is from groundwater ingestion and peaks near 1 at the end of institutional control. The marked increase in the groundwater ingestion hazard index at year 2010 (see Figure 6-19) is caused by the change in receptor location from the INL Site boundary to the SDA boundary.

- **Trichloroethylene**—Trichloroethylene was identified in screening performed after the simulations were complete (see Section 3.4.1). Values from OEHHA (2003) were used because EPA does not provide approved toxicity values for trichloroethylene. Risk for trichloroethylene is estimated by scaling carbon tetrachloride risk; therefore, a figure is not provided. The scaled inhalation risk is 9E-04 at the end of the institutional control period. Risk values for trichloroethylene will be computed and presented in the feasibility study.

6.4.2.3 **_Maximum Contaminant Levels._** Another indication of potential health risks is a comparison of predicted groundwater concentrations to MCLs. Maximum contaminant levels given in Table 6-8 are taken from "National Primary Drinking Water Regulations" (40 CFR 141). The MCL for alpha-emitting nuclides is 15 pCi/L total. The limit was used for individual radionuclides as an indication of the potential to exceed the MCL. The MCL for beta- and gamma-emitting radionuclides is based on a 4-mrem/year dose. Values used are taken from the 1977 rule as identified in EPA (2000). When comparing concentrations of uranium isotopes to the MCL of 30 µg/L for total uranium, time-consistent activities are converted to mass for each isotope and summed. Peak concentrations are simultaneous for the five uranium isotopes.

Simulated concentrations for I-129, Tc-99, carbon tetrachloride, methylene chloride, nitrate, and tetrachloroethylene exceed their respective MCLs within the 1,000-year simulation period. Carbon tetrachloride has been measured in the aquifer in concentrations greater than its MCL. Predicted concentrations of Tc-99 and I-129 for current groundwater concentrations are orders of magnitude greater than measured concentrations in the aquifer (see Section 5.2.5).

Table 6-8. Comparison of maximum groundwater concentrations to maximum contaminant levels for the 1,000-year simulation period.

Contaminant	Peak Concentration (pCi/L or mg/L)[a]	Peak Year	Maximum Contaminant Level (pCi/L or mg/L)[a]
Ac-227	5.30E-02	3010	15[b]
Am-241	6.80E-08	3010	15[b]
Am-243	1.29E-09	3010	15[b]
C-14	1.86E+02	2133	2,000
Cl-36	2.12E+01	2395	700
Cs-137	NA	NA	NA
I-129	1.31E+01	2111[c]	1
Nb-94	NA	NA	NA
Np-237	6.53-E02	3010	15[b]
Pa-231	8.17E-02	3010	15[b]
Pb-210	1.02E-05	3010	Not regulated
Pu-238	6.10E-19	2920	15[b]
Pu-239	5.19E-10	3010	15[b]
Pu-240	1.28E-10	3010	15[b]
Ra-226	1.30E-05	3010	5
Ra-228	1.97E-09	3010	5
Sr-90	NA	NA	NA
Tc-99	2.71E+03	2034[c]	900
Th-228	NA	NA	NA
Th-229	2.64E-02	3010	15[b]
Th-230	3.01E-04	3010	15[b]

Table 6-8. (continued).

Contaminant	Peak Concentration (pCi/L or mg/L)[a]	Peak Year	Maximum Contaminant Level (pCi/L or mg/L)[a]
Th-232	2.82E-09	3010	15[b]
U-233	2.90E+00	3010	2.9E+05[d]
U-234	3.97E-01	3010	1.87E+05[d]
U-235	1.19E-01	3010	6.49E+01[d]
U-236	6.24E-01	3010	1.94E+03[d]
U-238	5.52E-01	3010	1.01E+01[d]
Carbon tetrachloride	3.07E-01	2133	5.00E-03
1,4-Dioxane	1.69E-01	2111	3.00E-03[e]
Methylene chloride	5.85E-02	2245	5.00E-03
Nitrate	6.67E+01	2094[c]	10
Tetrachloroethylene	6.64E-02	2145	5.00E-03
Trichloroethylene	3.80E-02[f]	2130	5.00E-03
Total uranium	3.67E-03[g]	3010	3.00E-02

a. Units are pCi/L for radionuclides and mg/L for nonradionuclides.
b. The limit is 15 pCi/L for total alpha (40 CFR 141).
c. Peak occurs before the end of the 100-year institutional control period.
d. Limit is 3E-02 mg/L (30 µg/L) for total uranium. To compare concentrations of uranium isotopes, 3E-02 mg/L is converted to the equivalent activity for each isotope.
e. No maximum contaminant level is given, but a health advisory level is provided for reference.
f. The concentration was estimated by scaling from carbon tetrachloride.
g. This number is the peak concentration for total uranium in mg/L developed by converting activity for each uranium isotope to mass and summing the results.

NA = not applicable; Cs-137, Nb-94, Sr-90, and Th-228 were not evaluated for groundwater pathways.

The simulated 1,000-year peak concentration exceeds the maximum contaminant level for this contaminant.

6.4.2.4   Groundwater Risk Isopleths. Isopleths shown in Figures 6-20 through 6-24 illustrate peak groundwater risks and hazard indexes. Isopleths were generated by summing the risk from each contaminant in each grid block and then contouring these risks on the simulation grid. The maximum value, excluding the shaded grid blocks representing the area inside the SDA fence, is indicated below each figure, and the location of this maximum is indicated within each figure. Isopleths illustrate risk at the end of the simulated 100-year institutional control period, which coincides with the year of peak cumulative groundwater risk from all contaminants (i.e., when the receptor location is moved from the INL Site boundary to the SDA fence line).

Figure 6-20 shows the local (refined) grid, and Figure 6-21 shows the regional grid. Figure 6-22 shows the local grid risk isopleth for only VOCs (i.e., carbon tetrachloride, 1,4-dioxane, methylene chloride, and tetrachloroethylene; trichloroethylene is not included). The time of peak VOC risk outside the SDA occurs slightly later at year 2132. Figure 6-23 shows the cumulative hazard index isopleth for the peak hazard index, which also occurs at year 2132. The cumulative hazard index isopleth is attributable primarily to carbon tetrachloride.
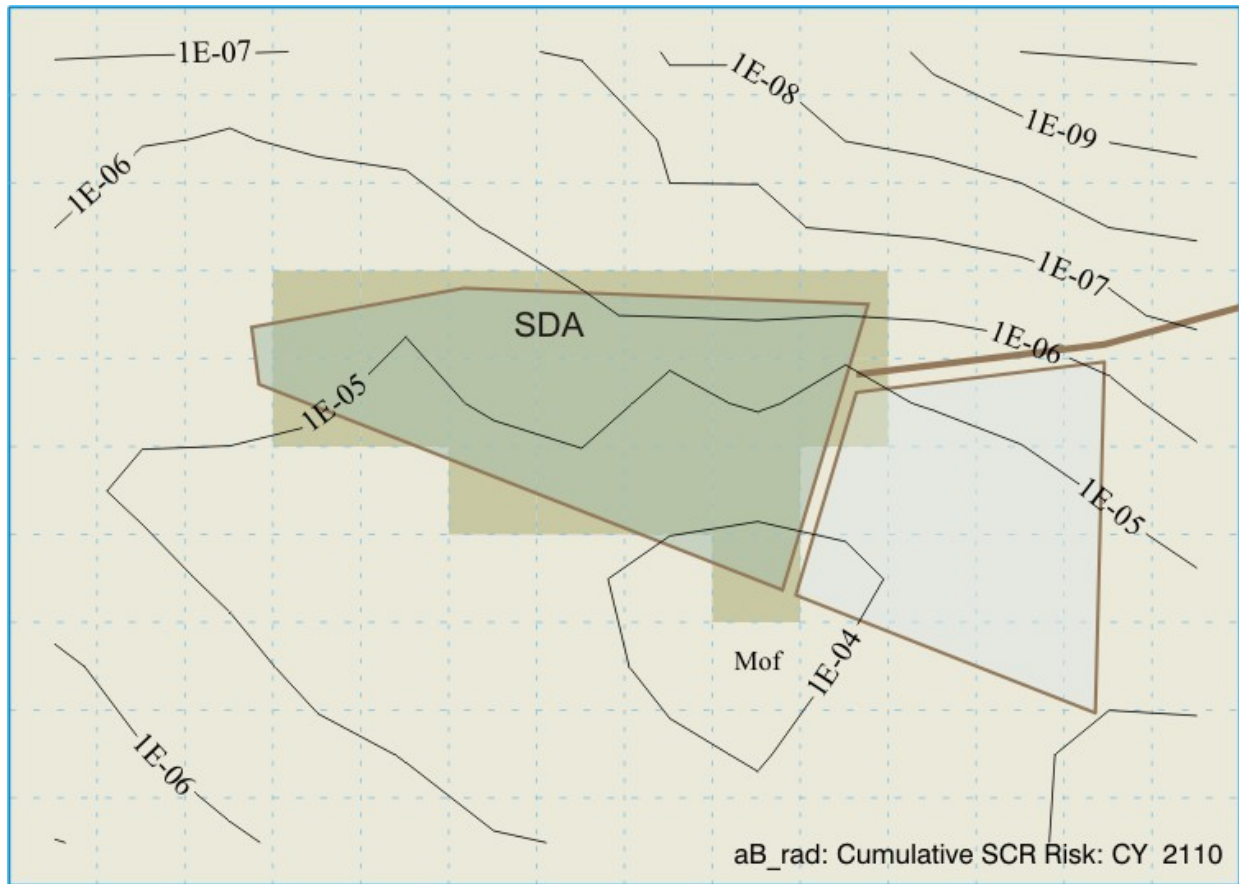
Mof = Maximum value outside fence = 2E-04

Figure 6-20. Cumulative groundwater ingestion risk isopleths for radionuclides at the end of the simulated 100-year institutional control period for the refined aquifer grid.
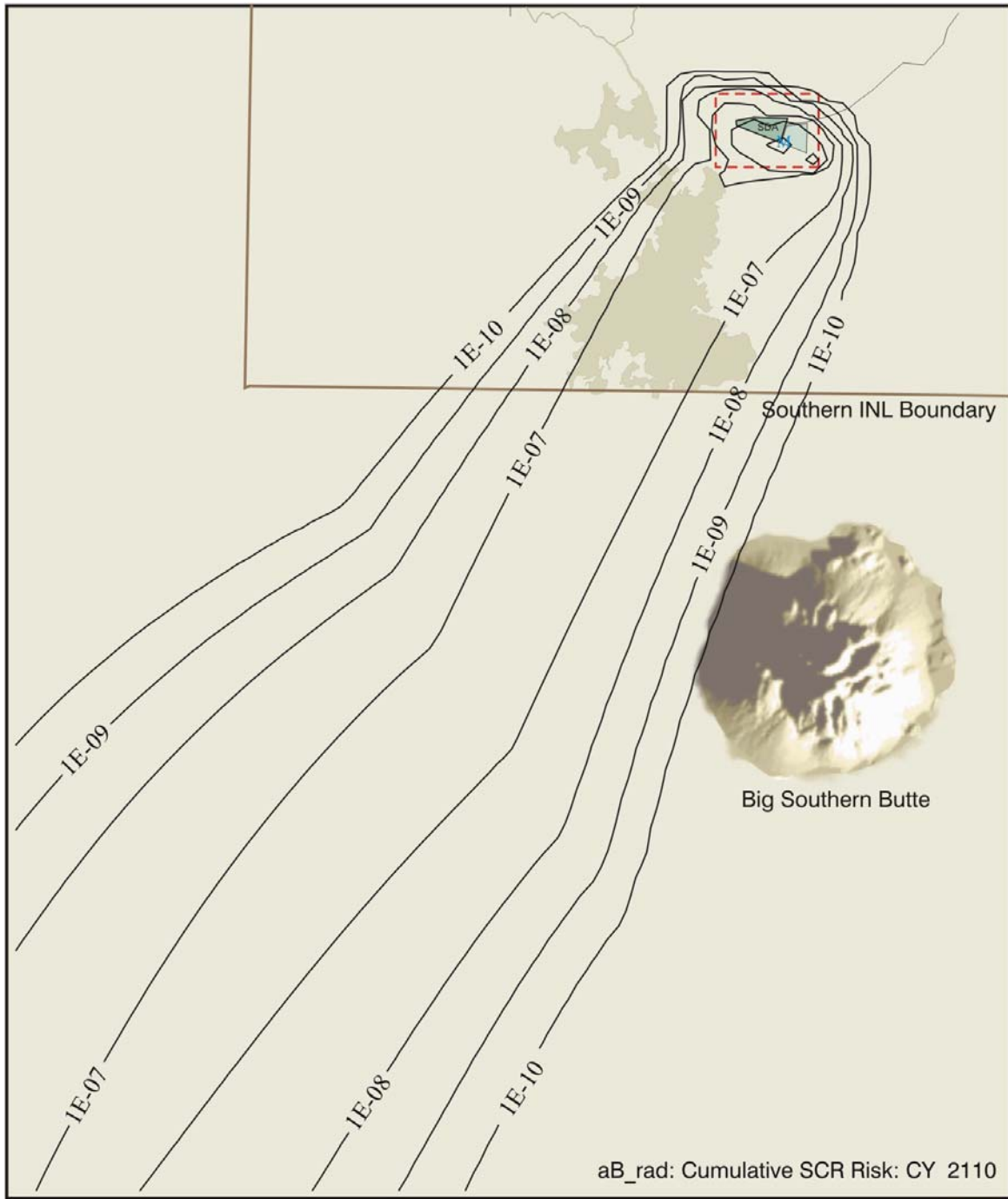
G1569-02

M = Maximum value = 2E-04

Figure 6-21. Cumulative groundwater ingestion risk isopleths for radionuclides at the end of the simulated 100-year institutional control period for the regional base aquifer grid.
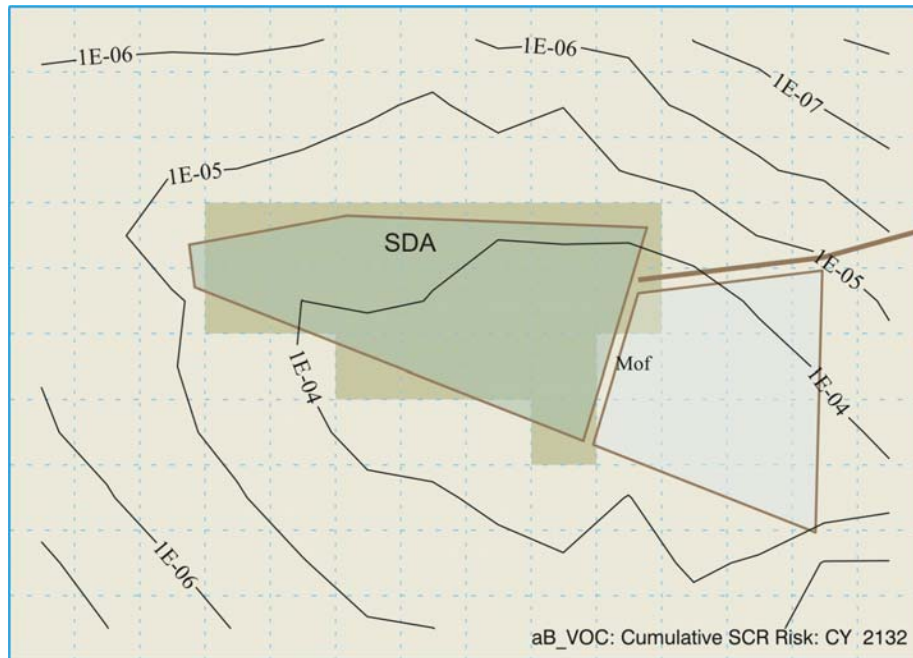
Mof = Maximum value outside fence = 5E-04

Figure 6-22. Peak cumulative groundwater ingestion risk isopleths for volatile organic compounds for the refined aquifer grid.
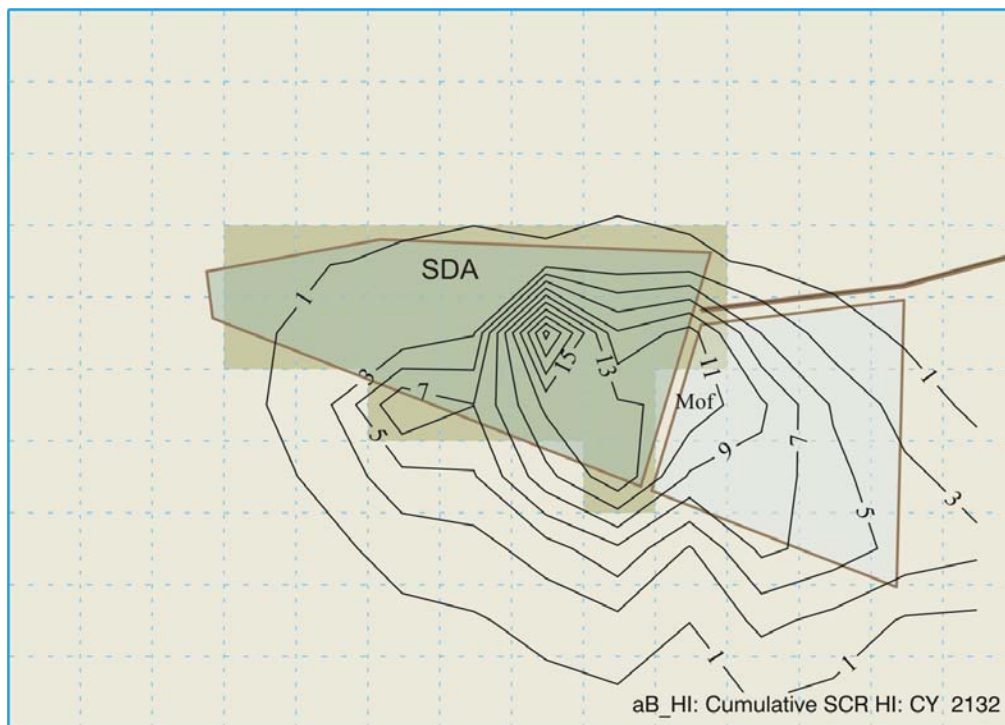
Mof = Maximum value outside fence = 1E+01

Figure 6-23. Peak cumulative groundwater ingestion hazard index isopleths for the refined aquifer grid.

6-60

Technetium-99 dominates the groundwater ingestion risk from radionuclides. As noted before, the measured concentrations are orders of magnitude below what the model predicts (see Section 5.2.5). Figure 6-24 shows cumulative risk isopleths for radionuclides without the Tc-99 contribution. The peak radionuclide risk still occurs in the year 2110, which is the end of the institutional control period. As shown in Figure 6-20, the model predicts that the 1E-04 risk does not extend very far from the SDA.

Mof = Maximum value outside fence = 5E-05
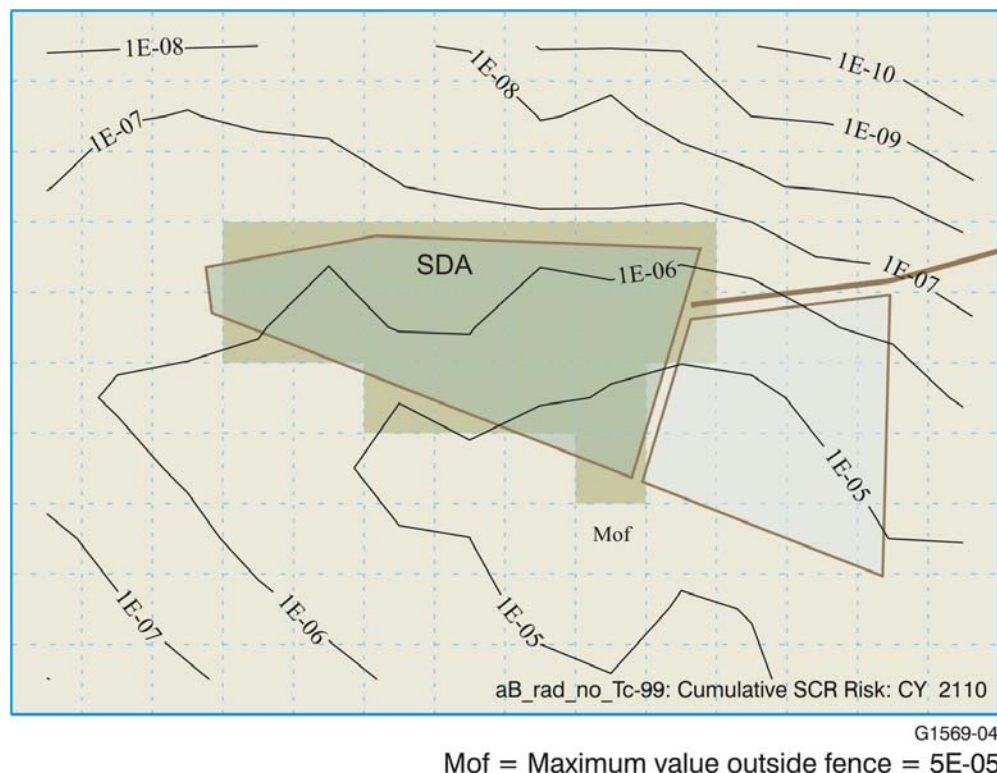
Figure 6-24. Peak cumulative groundwater ingestion risk isopleths for radionuclides (excluding technetium-99) for the refined aquifer grid.

6.4.2.5   **Summary.** Risk estimates are bounded by the residential scenario. Highest risk results from biotic uptake and eventual exposure to radionuclides brought to the surface. Primary isotopes that cause surface exposure risk are Am-241, Cs-137, Pb-210, Pu-239, Pu-240, Ra-226, Ra-228, Sr-90, and Th-228.

Groundwater risk is dominated by carbon tetrachloride and Tc-99, with smaller contributions from C-14, I-129, Tc-99, and 1,4-dioxane. Simulated concentrations that exceed their respective MCLs include I-129, Tc-99, carbon tetrachloride, 1,4-dioxane, methylene chloride, nitrate, and tetrachloroethylene. Simulated concentrations and risks attributable to Tc-99 and I-129 are not corroborated by monitoring data, and risk attributable to trichloroethylene has not been fully evaluated. (Note: Section 7 contains the recommendation to refine evaluation of these contaminants in the feasibility study.) Cumulative groundwater isopleths illustrate that risk and hazard indexes greater than 1E-04 and 1, respectively, are limited to the region immediately around the SDA. Risk at the INL Site boundary does not exceed 1E-06, even if overestimated risks for I-129 and Tc-99 are included.

6.4.3 10,000-Year Groundwater Ingestion Risks

Simulations were extended to 10,000 years because 1,000-year simulations did not reach peak groundwater concentrations for some radionuclides. Residential scenario risk estimates are greater than 1E-05 in the 10,000-year simulation period for eight radionuclides. Figure 6-25 shows the groundwater ingestion risk for all eight isotopes. The following subsections summarize residential scenario risks, compare simulated groundwater concentrations to MCLs, and present groundwater risk isopleths.
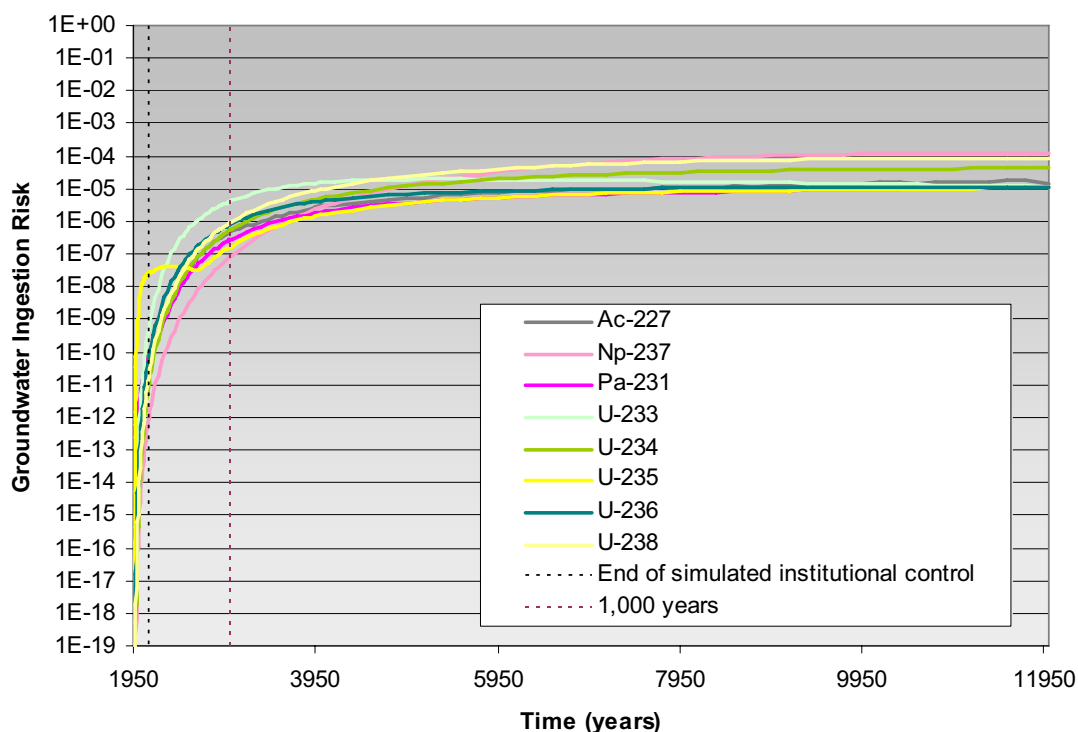
Figure 6-25. Simulated 10,000-year groundwater ingestion risk for contaminants that peak after 1,000 years.

6.4.3.1   Residential Scenario Groundwater Ingestion Risk. Risk attributable to residential groundwater use was assessed using the same modeling approach and risk assessment parameters (e.g., exposure duration and slope factors) as applied for the 1,000-year simulation period. The receptor location is the SDA boundary. Eight radionuclides have risk estimates in the 10,000-year period greater than 1E-05, as summarized in the following list (see Table 6-9):

- **Ac-227**—Ac-227 is produced by decay of Pu-239 and U-235. Because Ac-227 has a relatively short half-life, long-term risk is driven by parents in the decay chain. The risk from both Ac-227 and Pa-231 comes from the decay of U-235. The peak groundwater ingestion risk for Ac-227 is 2E-05 at the end of the 10,000-year simulation period.

- **Np-237**—Np-237 is produced from decay of Am-241 and Pu-241. The peak groundwater ingestion risk for Np-237 is 1E-04 at the end of the 10,000-year simulation period.

- **Pa-231**—Pa-231 is produced from decay of Pu-239 and U-235. The peak groundwater ingestion risk for Pa-231 is 1E-05 at the end of the 10,000-year simulation period.

- **U-233**—Some U-233 was buried in the SDA, but most U-233 is from decay of Np-237. Risk occurs substantially sooner than for other long-term contaminants, partly because total uranium solubility is used in the simulation for U-233 instead of isotope-specific solubilities used for U-234, U-235, and U-238. This allows U-233 mass to release more rapidly relative to other uranium isotopes. The peak groundwater ingestion risk for U-233 is 2E-05 near the year 5350.

- **U-234**—Some U-234 was buried in the SDA, but most U-234 is produced from decay of Pu-238 and U-238. The peak groundwater ingestion risk for U-234 is 4E-05 at the end of the 10,000-year simulation period.

- **U-235**—Some U-235 was buried in the SDA, but most U-235 is produced from decay of Pu-239. The peak groundwater ingestion risk for U-235 is 1E-05 at the end of the 10,000-year simulation period.

- **U-236**—Some U-236 was buried in the SDA, but most U-236 is produced from decay of Pu-240. The peak groundwater ingestion risk for U-236 is 1E-05 at the end of the 10,000-year simulation period.

- **U-238**—U-238 was contained in waste produced primarily at Rocky Flats Plant. The peak groundwater ingestion risk for U-238 is 9E-05 at the end of the 10,000-year simulation period.

6.4.3.2 Maximum Contaminant Levels. Table 6-9 compares simulated groundwater concentrations to MCLs for the 10,000-year simulation period. The MCL for alpha-emitting nuclides is 15 pCi/L total, which is the limit used for individual radionuclides as an indicated potential to exceed the limit. The MCL for total uranium is 30 µg/L. To assess simulated concentrations for uranium isotopes against the total uranium MCL, activities for each isotope are converted to mass and summed, and the total is compared to 30 µg/L. Total uranium exceeds the 30 µg/L MCL due to the simulated U-238 concentration in the aquifer.

6.4.3.3 10,000-Year Groundwater Risk Isopleths. Isopleths in Figures 6-26 and 6-27 illustrate peak cumulative groundwater risk, which occurs at the end of the 10,000-year groundwater simulation period. Isopleths were generated by summing the risk from each contaminant in each grid block and then contouring these risks on the simulation grid. The maximum value, excluding the shaded grid blocks representing the area inside the SDA fence, is indicated below each figure, and the location of this maximum value is indicated within the figure. The local (refined) grid is shown in Figure 6-26, and the regional grid is shown in Figure 6-27. The local grid shows peak risk of 3E-04 in the immediate vicinity of RWMC. The regional grid shows that the maximum risk at the INL Site boundary is less than 1E-06.

Table 6-9. Comparison of maximum groundwater concentrations to maximum contaminant levels for the 10,000-year simulation period.

Contaminant	Peak Risk	Peak Concentration (pCi/L)	Peak Calendar Year	Maximum Contaminant Level[a]
Ac-227	2E-05	2.31E+00	12000	15[b]
Np-237	1E-04	8.68E+01	12000	15[b]
Pa-231	1E-05	3.20E+00	12000	15[b]
U-233	2E-05	1.30E+01	5000	2.9E+05[c]
U-234	4E-05	2.71E+01	12000	1.87E+05[c]
U-235	1E-05	7.18E+00	12000	6.49E+01[c]
U-236	1E-05	8.29E+00	12000	1.94E+03[c]
U-238	9E-05	4.71E+01	12000	1.01E+01[c]
Total uranium	NA	1.44E-01[d]	12000	3.00E-02[d]

a. Maximum contaminant levels are taken from "National Primary Drinking Water Regulations" (40 CFR 141).
b. The limit is 15 pCi/L for total alpha (40 CFR 141).
c. The limit is 3E-02 mg/L (30 µg/L) for total uranium. To compare concentrations of uranium isotopes, 3E-02 mg/L is converted to the equivalent activity for each isotope.
d. This number is the peak concentration for total uranium in mg/L developed by converting activity for each uranium isotope to mass and summing the results, regardless of the timing of the peak.

The simulated 10,000-year peak concentration exceeds the maximum contaminant level for this contaminant.
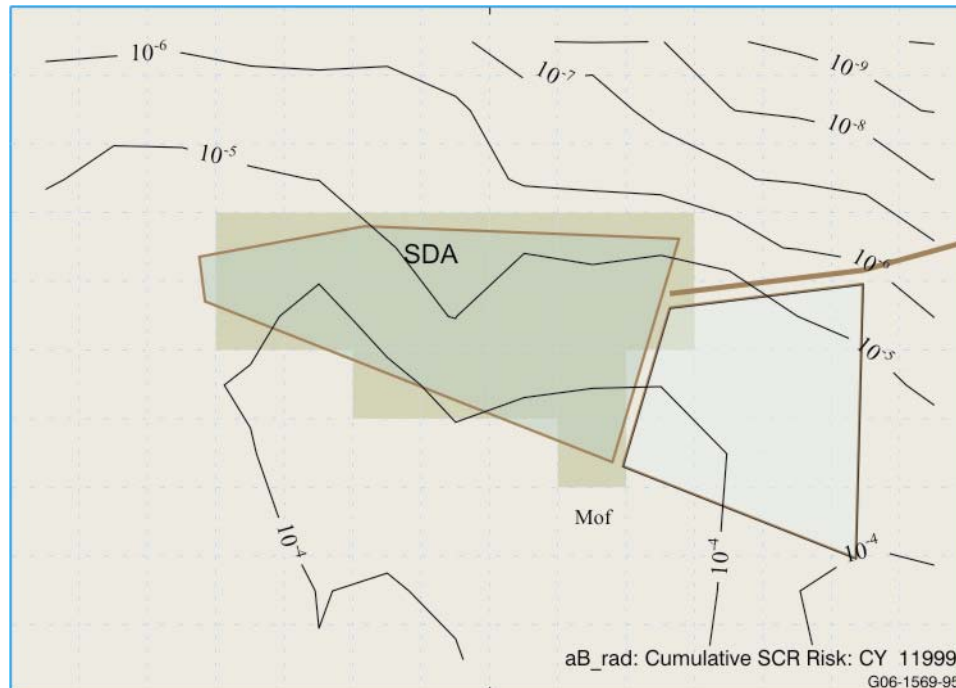
Mof=Max value outside fence=3.15E-004

Figure 6-26. Total peak groundwater risk isopleths at the end of the 10,000-year groundwater simulation period for the local refined grid.
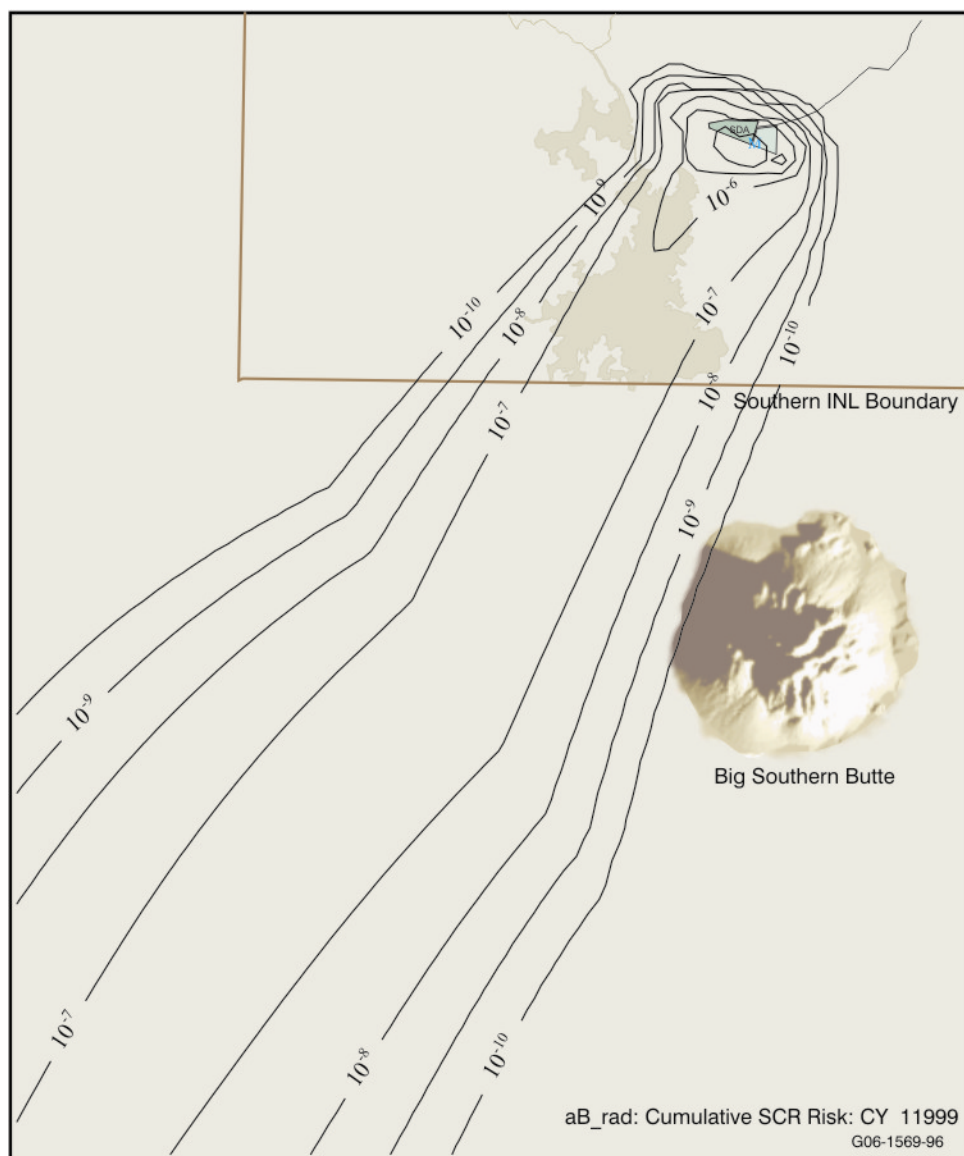
M=Max value=2.8E-004

Figure 6-27. Total peak groundwater risk isopleths at the end of the 10,000-year groundwater simulation period for the regional refined grid.

6.4.4 Risk and Concentration Plots

Figures 6-28 through 6-94 illustrate media concentrations, risks, and hazard indexes throughout the simulation period. Results are organized by simulation groups. The groups represent primary nuclides and their daughter products (see Table 5-8 for more details) as follows:

- **Group 1**—Am-241, Np-237, U-233, and Th-229.

- **Group 2**—Am-243, Pu-239, U-235, Pa-231, and Ac-227.

- **Group 3**—Pu-240, U-236, Th-232, and Ra-228.

- **Group 4**—Pu-238, U-234, Th-230, Ra-226, and Pb-210.

- **Group 5**—U-238, U-234, Th-230, Ra-226, and Pb-210.

- **Group 6**—Tc-99, I-129, and Cl-36. (Note: Refined results for Tc-99 and I-129 will be presented in the feasibility study.)

- **Group 7**—Tritium. (Note: Tritium is not presented because it is not a contaminant of potential concern and, therefore, was not evaluated for risk. Group 7 was originally defined strictly for assessing dual-phase model performance and was subsequently excluded from analysis [see Section 5.2.5].)

- **Group 8**—C-14.

- **Group 9**—Cs-137, Nb-94, Sr-90, and Th-228. (Note: Surface exposure pathways are addressed only, no groundwater simulations are addressed.)

- **Group 10**—Nitrate. (Note: Chromium is included in Group 10 simulations, but is not presented here because it is not a contaminant of potential concern and, therefore, was not evaluated for risk.)

- **Group 11**—Carbon tetrachloride, 1,4-dioxane, methylene chloride, and tetrachloroethylene. (Note: Trichloroethylene will be evaluated in the feasibility study.)

Figures 6-28 through 6-94 present the plots described in this paragraph. Seven plots each are presented for simulation Groups 1, 2, 3, 4, 5, 6, 8, 10, and 11. Group 7 (i.e., tritium) contains no contaminants of potential concern and is not presented. Group 9 contaminants (i.e., Cs-137, Nb-94, Sr-90, and Th-228) are evaluated only for surface exposure pathways because groundwater exposures are not relevant; therefore, only three plots are presented for Group 9. Plots are presented as follows:

- Estimated total risk for the hypothetical future residential scenario from all exposure pathways for the 1,000-year simulation period

- Simulated groundwater concentrations outside the SDA for the 10,000-year simulation period (excluding Group 9)

- Simulated groundwater risks outside the SDA for the 10,000-year simulation period (excluding Group 9)

- Simulated groundwater concentrations at the INL Site boundary for the 10,000-year simulation period (excluding Group 9)

- Estimated groundwater ingestion risk at the INL Site boundary for the 10,000-year simulation period (excluding Group 9)

- Simulated soil concentrations next to the SDA for the 1,000-year simulation period

- Occupational scenario risks for the 1,000-year simulation period.

All isotopes within each group are presented, though a few isotopes are not contaminants of potential concern. These additional contaminants, which are long-lived decay-chain products within contaminant groups, are presented for completeness. Total risk from all pathways for the hypothetical

future residential scenario is presented for 1,000 years. The marked increase in risk plots at year 2110 indicates when the residential receptor location moves from the INL Site boundary to the SDA boundary. Also, additional pathways are complete at that time, thus increasing total risk. Groundwater ingestion risks before the year 2110 (end of institutional control) are computed at the INL Site boundary and may be too small to show on the scale of the total risk plot. Risks from surface pathway exposures are greater than in previous assessments (Holdren et al. 2002; Becker et al. 1998) because of the change to the biotic modeling (see Section 5.5). This change makes more mass available for uptake early in the simulation period and, hence, produces much larger surface pathway risks.

Groundwater concentrations and risks are presented for 10,000 years for both the SDA and INL Site boundaries. Risks at the SDA boundary before the end of institutional control are shown for comparison purposes only; the region within the INL Site (e.g., at the SDA boundary) is not available for residential use.

Estimated soil concentrations are shown for the 1,000-year simulation period. Soil concentrations change rapidly after the end of institutional control for some contaminants. Unlike groundwater ingestion, this is not the result of a change in receptor location. This change is caused by biota reverting to native plant and animal communities, allowing deeper rooting plants and large burrowing animals to inhabit the SDA. Change does not occur instantaneously; the slight delay in the change occurs as ecological communities revert from current conditions to native communities.

Occupational risks are presented for the 1,000-year simulation period. Groundwater ingestion is not an occupational exposure pathway; therefore, plots tend to follow soil concentration curves for various contaminants. The exception is vapor inhalation risk for carbon tetrachloride and C-14. Vapor inhalation drives early risk for those contaminants because of high mobility of the vapor phase.

6.4.4.1   *Group 1 Contaminants.* This subsection provides simulated risk and concentration plots for Group 1 contaminants, which comprise the Am-241 decay chain (i.e., Am-241, Np-237, U-233, and Th-229). Figures 6-28 through 6-34 present results for Group 1. Americium-241 has the highest residential risk, which peaks at 3E-03 in the year 2594 and is primarily attributable to surface exposure pathways. Peak groundwater ingestion risks are from Np-237 and U-233 in the 10,000-year simulation period. Risk from U-233 is likely to be overestimated because the solubility limit for total uranium was applied to U-233. In reality, U-233 is a minor component of total uranium. Because the relative amount of U-233 changes with time, simulations used the conservative assumption on solubility. Occupational risk shows a change in slope after the end of institutional control attributable to return to a native community; deeper rooting plants and larger burrowing animals increase uptake to the surface where the occupational receptor can be exposed.

Figure 6-28. Total carcinogenic risk for Group 1 contaminants for hypothetical future residential exposure pathways for the 1,000-year simulation period.

Figure 6-29. Simulated maximum groundwater concentrations for Group 1 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.

Figure 6-30. Simulated groundwater ingestion risk for Group 1 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.

Figure 6-31. Simulated maximum groundwater concentrations for Group 1 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.

Figure 6-32. Simulated maximum groundwater ingestion risk for Group 1 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.

Figure 6-33. Simulated soil concentrations for Group 1 contaminants.
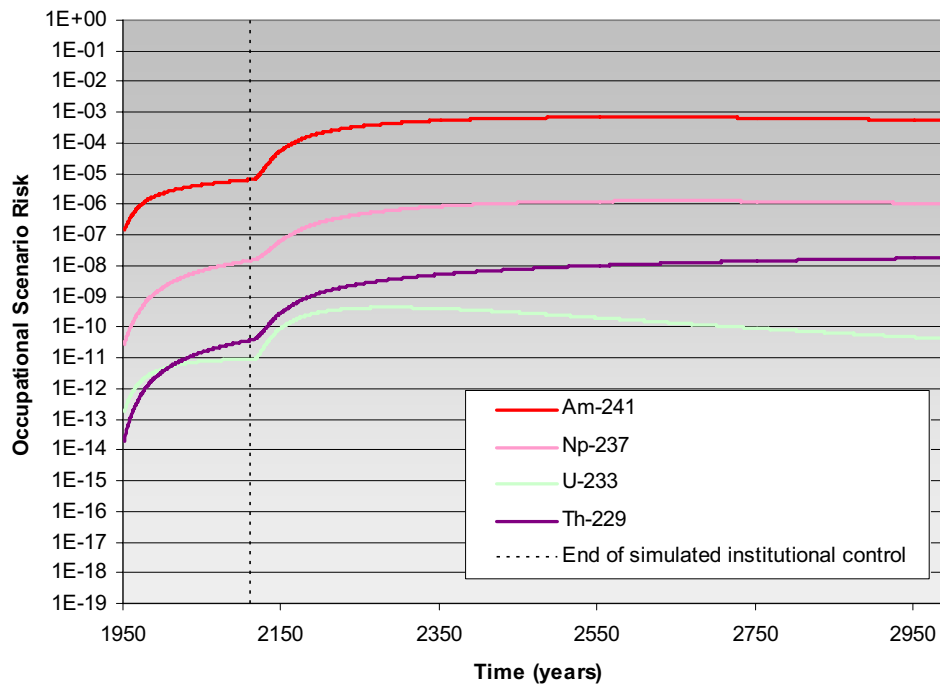
Figure 6-34. Simulated total carcinogenic risk for Group 1 contaminants for hypothetical future occupational scenario exposure pathways.

6.4.4.2   *Group 2 Contaminants.* This subsection provides the simulated risk and concentration plots for Group 2 contaminants, which comprise the Am-243 decay chain (i.e., Am-243, Pu-239, U-235, Pa-231, and Ac-227). Figures 6-35 through 6-41 present results for Group 2. Residential scenario risk is dominated by the Pu-239 risk attributable to surface exposure pathways (i.e., soil ingestion, crop ingestion, and inhalation of fugitive dust). None of the other contaminants peak above 1E-06. Uranium-235, Pa-231, and Ac-227 have peak groundwater ingestion risks greater than 1E-05 for the 10,000-year simulation period at the SDA boundary and less than 1E-07 at the INL Site boundary. Groundwater ingestion risk for U-235 is lower and occurs later than presented in the ABRA because the mobility of uranium is reduced and the solubility of uranium is included in release calculations. The soil-to-water partition coefficient increased from 6 to 15.4. Solubility of U-235 was computed by distributing total uranium solubility by the ratio of the mass of U-235 to the total mass of uranium. Occupational risk shows a change in slope after the end of institutional control attributable to return to a native community; deeper rooting plants and larger burrowing animals increase uptake to the surface where the occupational receptor can be exposed.

Figure 6-35. Total carcinogenic risk for Group 2 contaminants for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.

Figure 6-36. Simulated maximum groundwater concentrations for Group 2 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.
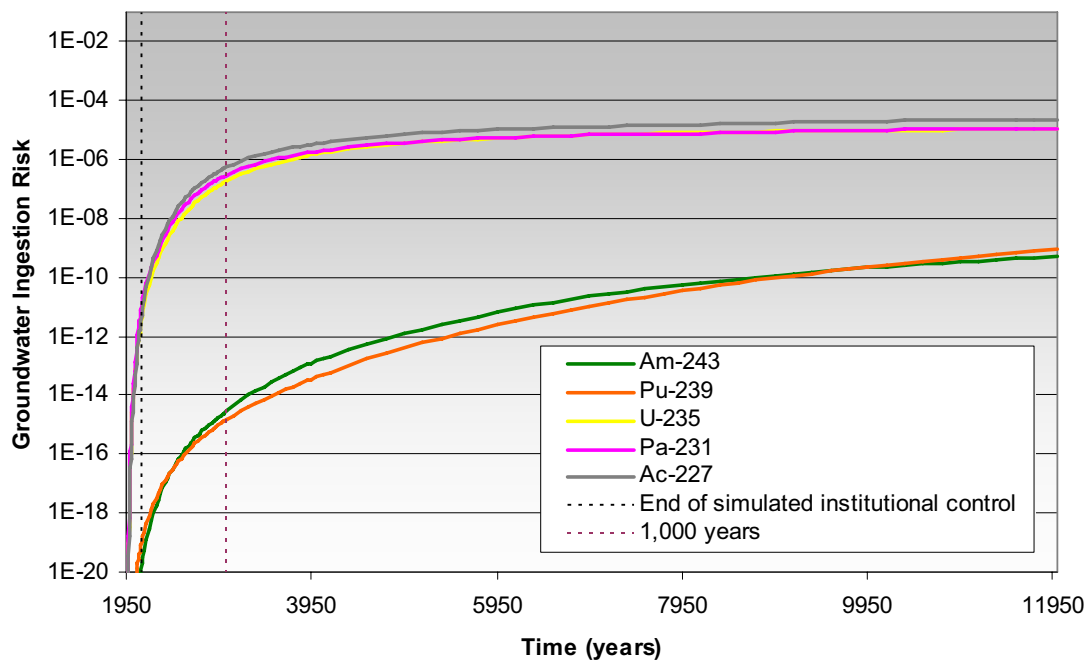
Figure 6-37. Simulated groundwater ingestion risk for Group 2 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.
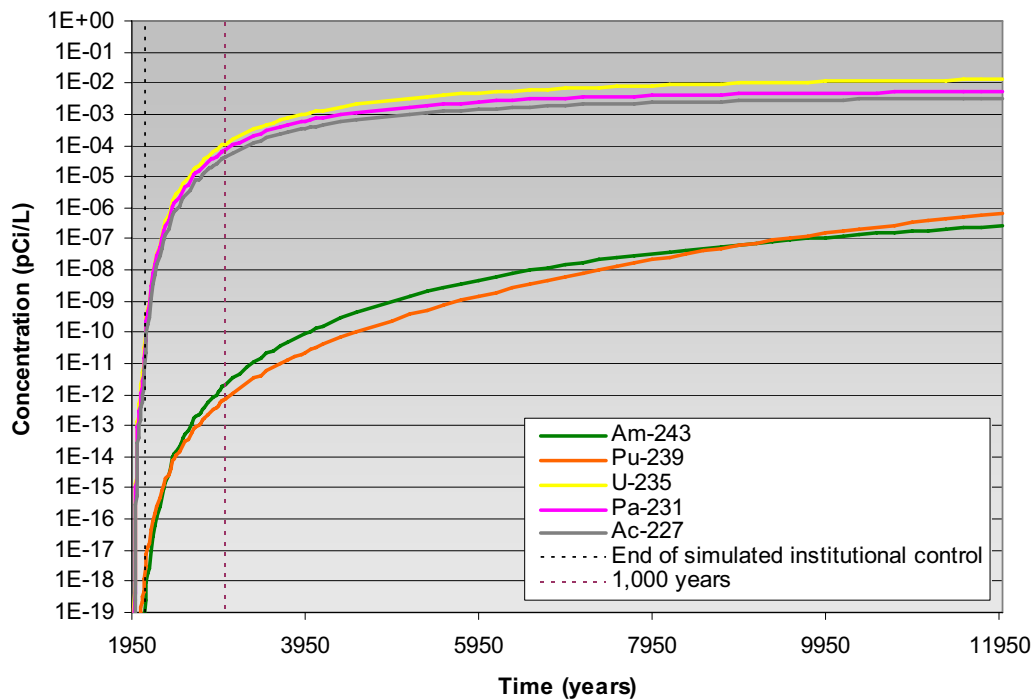
Figure 6-38. Simulated maximum groundwater concentrations for Group 2 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
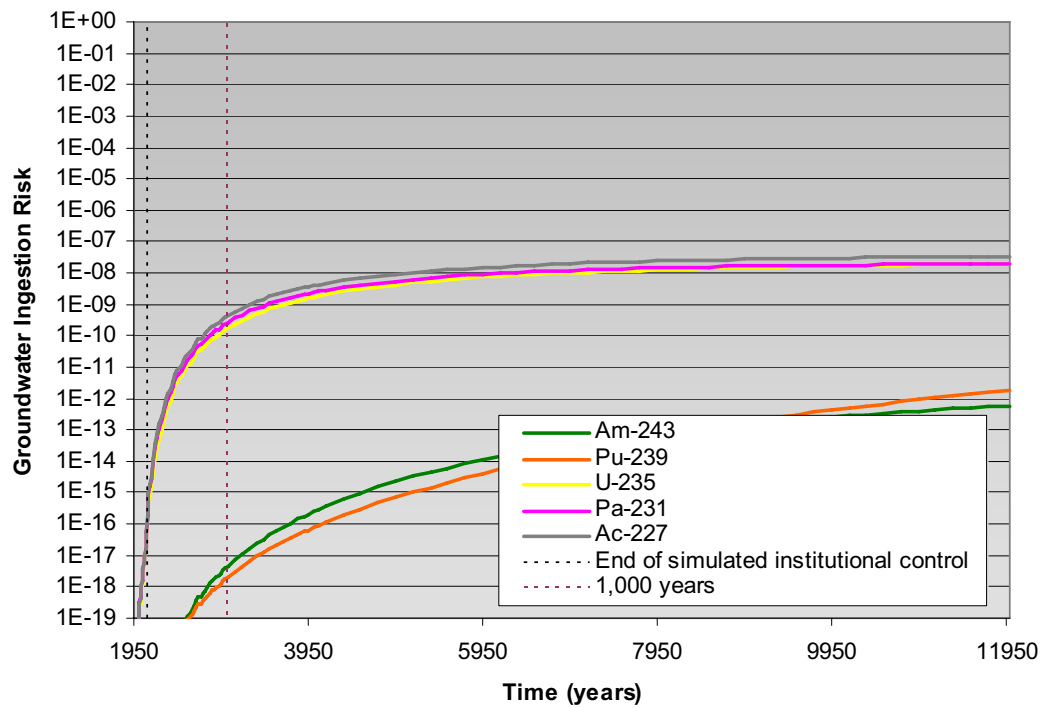
Figure 6-39. Simulated maximum groundwater ingestion risk for Group 2 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
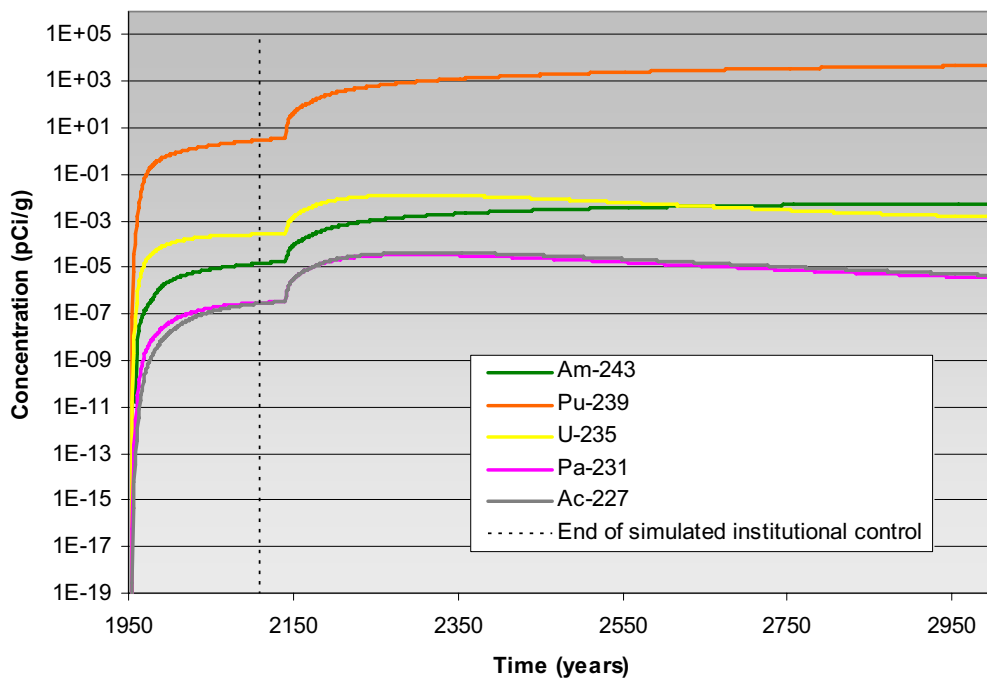
Figure 6-40. Simulated soil concentrations for Group 2 contaminants.
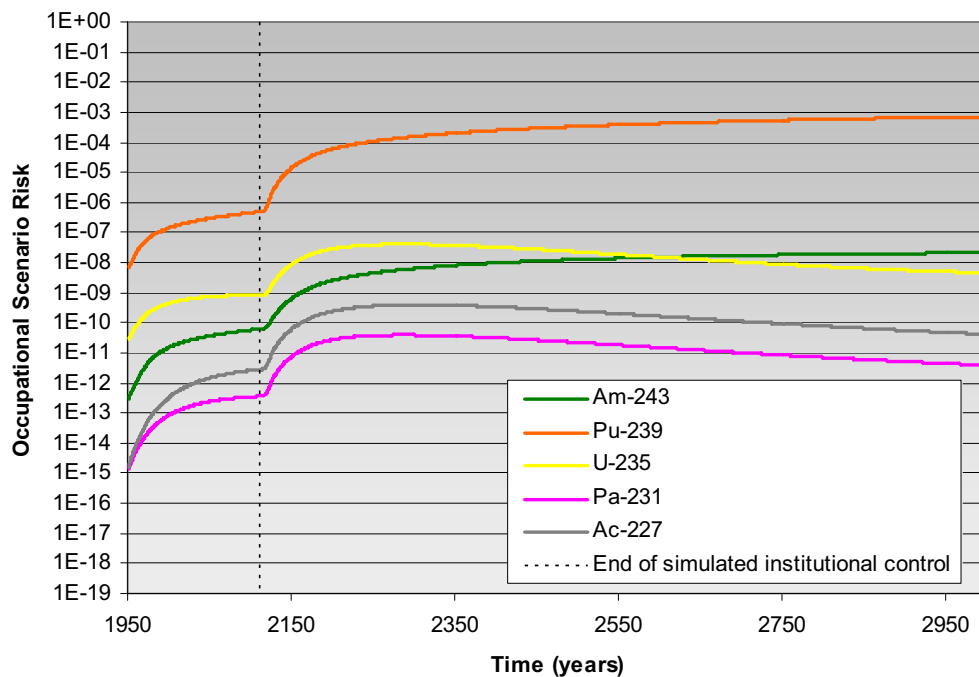
Figure 6-41. Simulated risk for a hypothetical future occupational scenario for Group 2 contaminants.

6.4.4.3   Group 3 Contaminants. This subsection provides simulated risk and concentration plots for Group 3 contaminants, which comprise the Pu-240 decay chain (i.e., Pu-240, U-236, Th-232, and Ra-228). Figures 6-42 through 6-48 present simulation results. Total risk is dominated by the Pu-240 risk attributable to surface exposure pathways (i.e., soil ingestion, crop ingestion, and inhalation of fugitive dust). Risk from external exposure to Ra-228 also exceeds 1E-05. Groundwater ingestion risk from U-236 peaks at 1E-06 at the SDA boundary and is less than 1E-07 at the INL Site boundary. Groundwater ingestion risk from U-236 is lower and later in time compared to the ABRA because of the change in mobility and solubility limit for total uranium used in this assessment. Occupational risk shows a change in slope after the end of institutional control attributable to return to a native community; deeper rooting plants and larger burrowing animals increase uptake to the surface where the occupational receptor can be exposed.

Figure 6-42. Total carcinogenic risk for Group 3 contaminants for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.

Figure 6-43. Simulated maximum groundwater concentrations for Group 3 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.

Figure 6-44. Groundwater ingestion risk at the Subsurface Disposal Area boundary for Group 3 contaminants for the 10,000-year simulation period.

Figure 6-45. Simulated maximum groundwater concentrations for Group 3 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.

Figure 6-46. Simulated maximum groundwater ingestion risk for Group 3 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
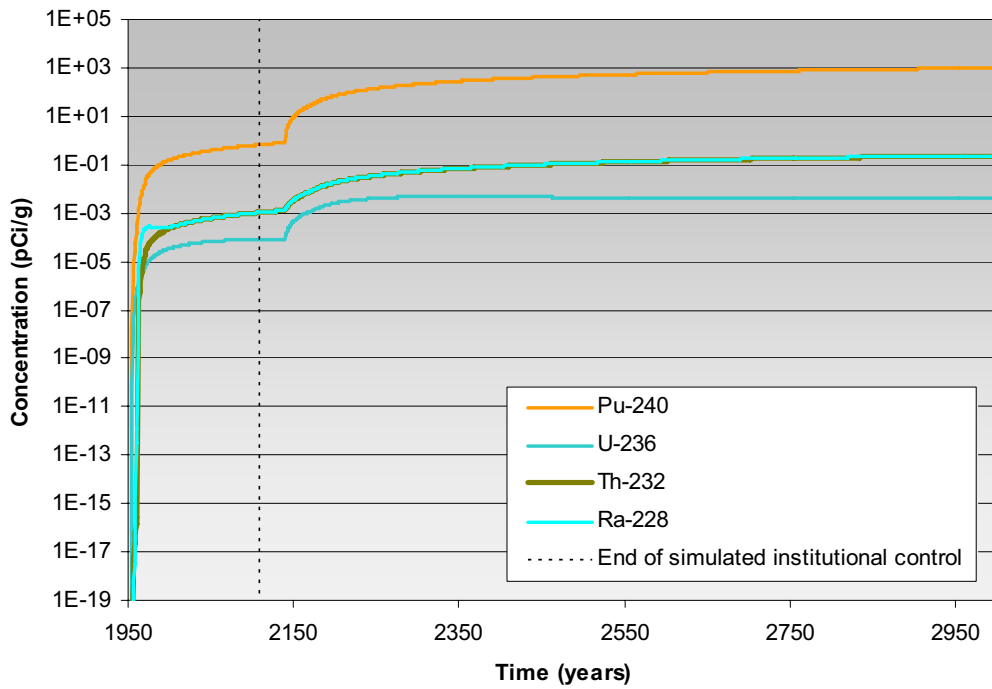
Figure 6-47. Simulated soil concentrations for Group 3 contaminants.
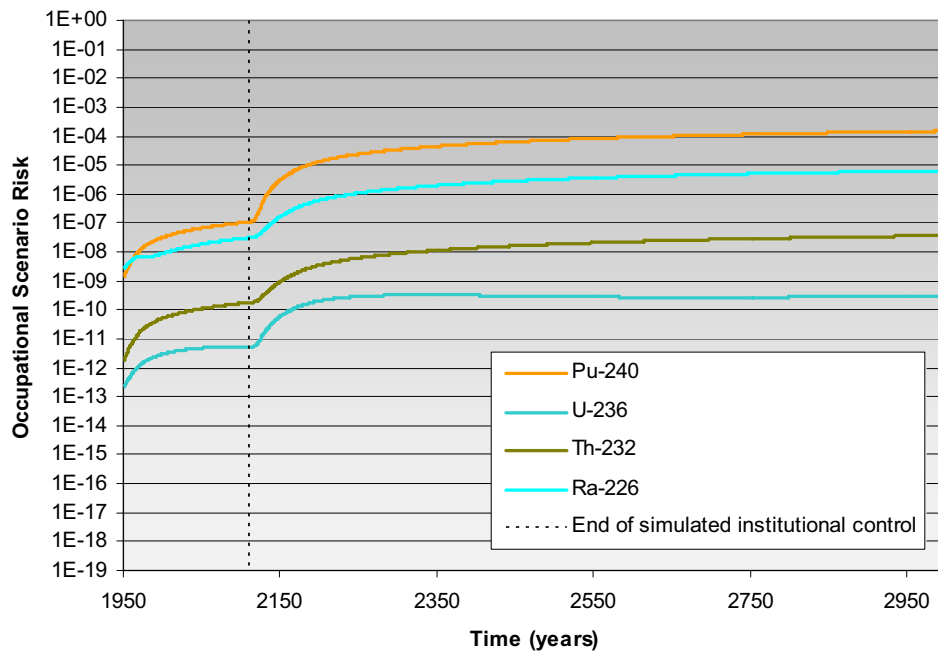
Figure 6-48. Simulated risk for a hypothetical future occupational scenario for Group 3 contaminants.

6.4.4.4   *Group 4 Contaminants.* This subsection provides simulated risk and concentration plots for Group 4 contaminants, which comprise the Pu-238 decay chain (i.e., Pu-238, U-234, Th-230, Ra-226, and Pb-210). Figures 6-49 through 6-55 present the simulation results. Members of the Pu-238 decay chain (i.e., U-234, Th-230, Ra-226, and Pb-210) also are included in Group 5, which comprises the U-238 decay chain. Risks shown in this section for U-234, Th-230, Ra-226, and Pb-210 are attributable to decay of Pu-238. Contributions from the U-238 decay chain and associated quantities of U-234, Th-230, Ra-226, and Pb-210 are presented under Group 5. Plutonium-238 is the primary contributor to the total risk from Group 4. Risk peaks at 1E-06 in the year 2262. Because of its short half-life, the risk drops after that time. Primary groundwater ingestion risk is from U-234, which peaks below 1E-05. Groundwater ingestion risk from U-234 is reduced later in time than was shown in the ABRA because of the lower mobility and the solubility limit used for total uranium. Peak groundwater risk at the INL Site boundary is less than 1E-08. Occupational risk shows a change in slope after the end of institutional control attributable to return to a native community; deeper rooting plants and larger burrowing animals increase uptake to the surface where the occupational receptor can be exposed.
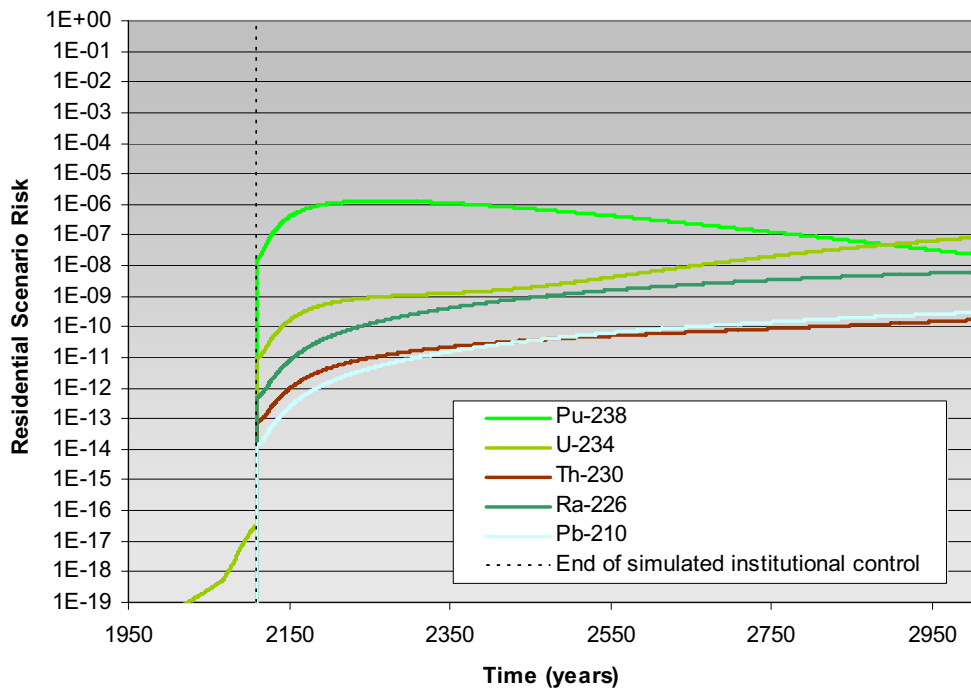
Figure 6-49. Total carcinogenic risk for Group 4 contaminants for hypothetical future residential exposure pathways for the 1,000-year simulation period.
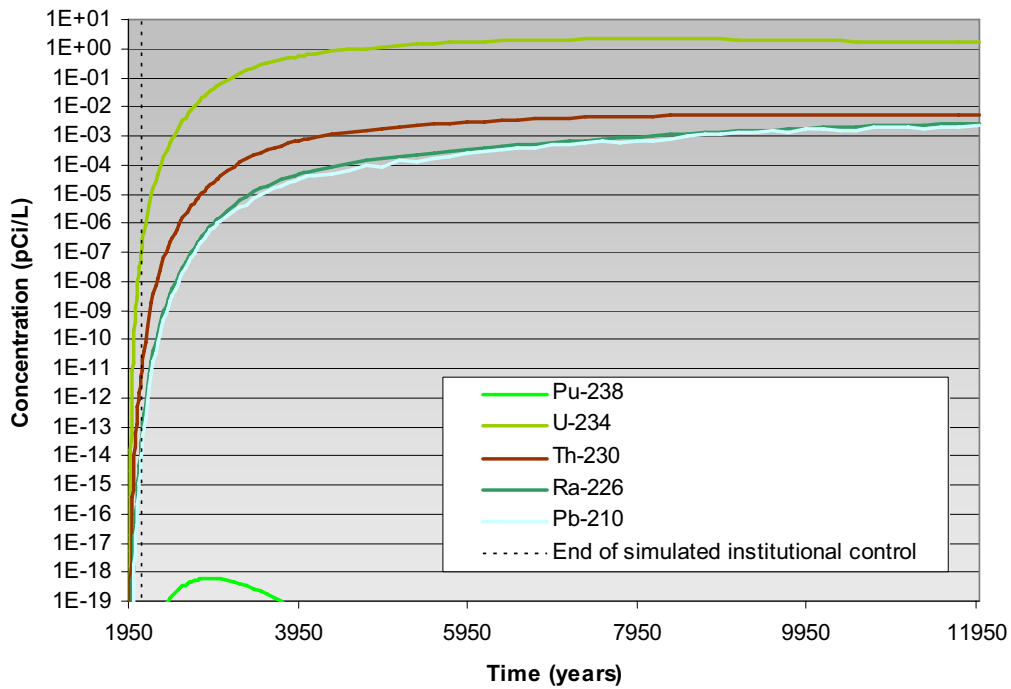
Figure 6-50. Simulated maximum groundwater concentrations for Group 4 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.
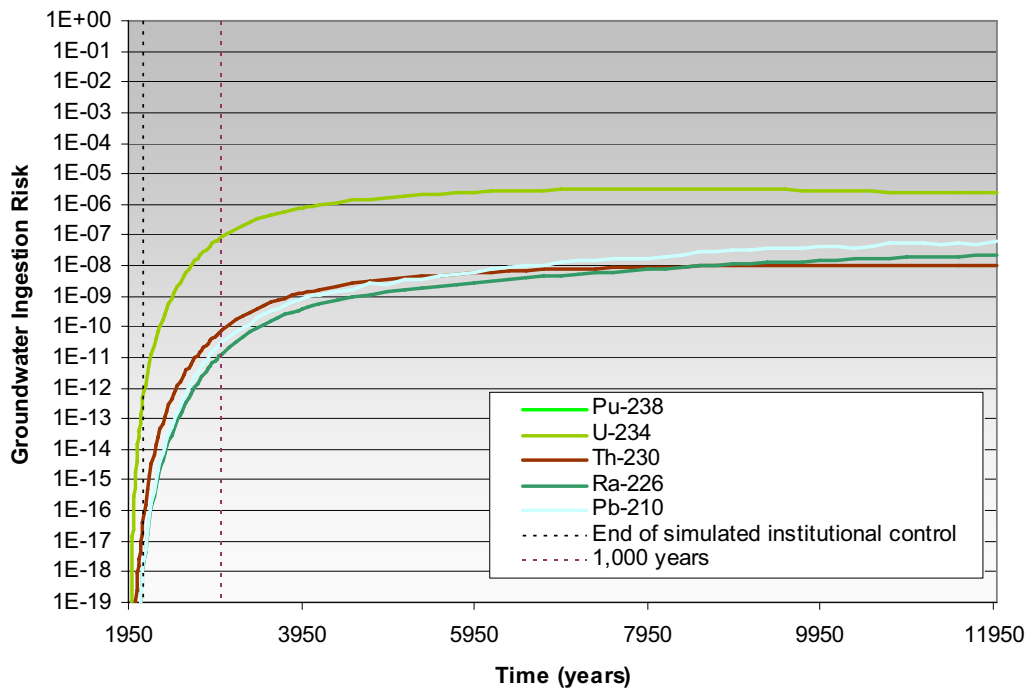
Figure 6-51. Groundwater ingestion risk at the Subsurface Disposal Area boundary over 10,000 years for Group 4 contaminants.
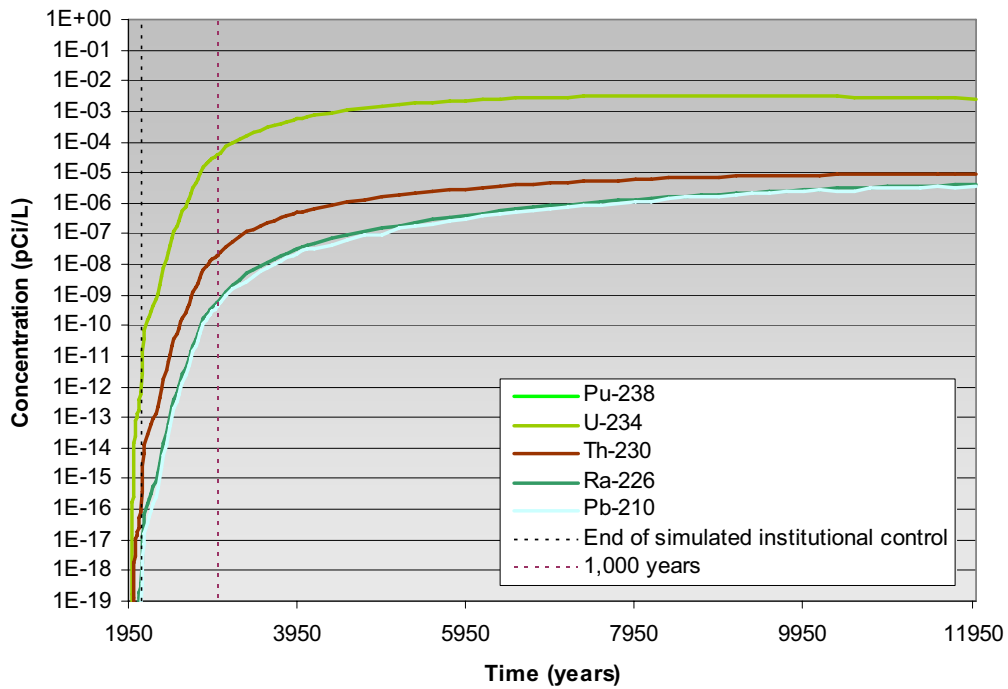
Figure 6-52. Simulated maximum groundwater concentrations for Group 4 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
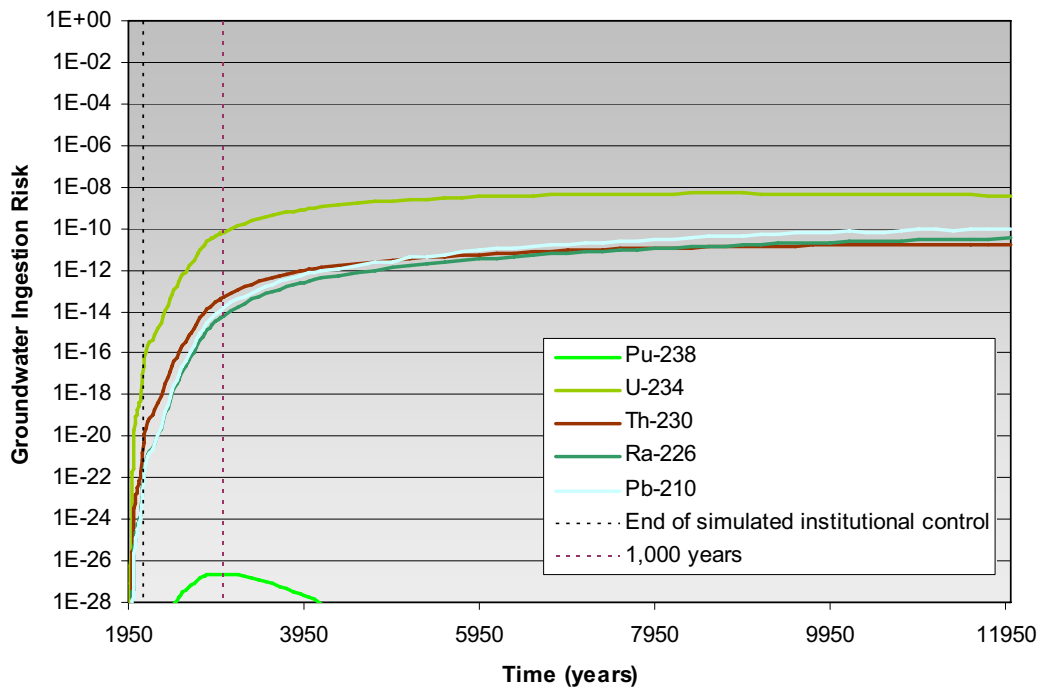
Figure 6-53. Simulated maximum groundwater ingestion risk for Group 4 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
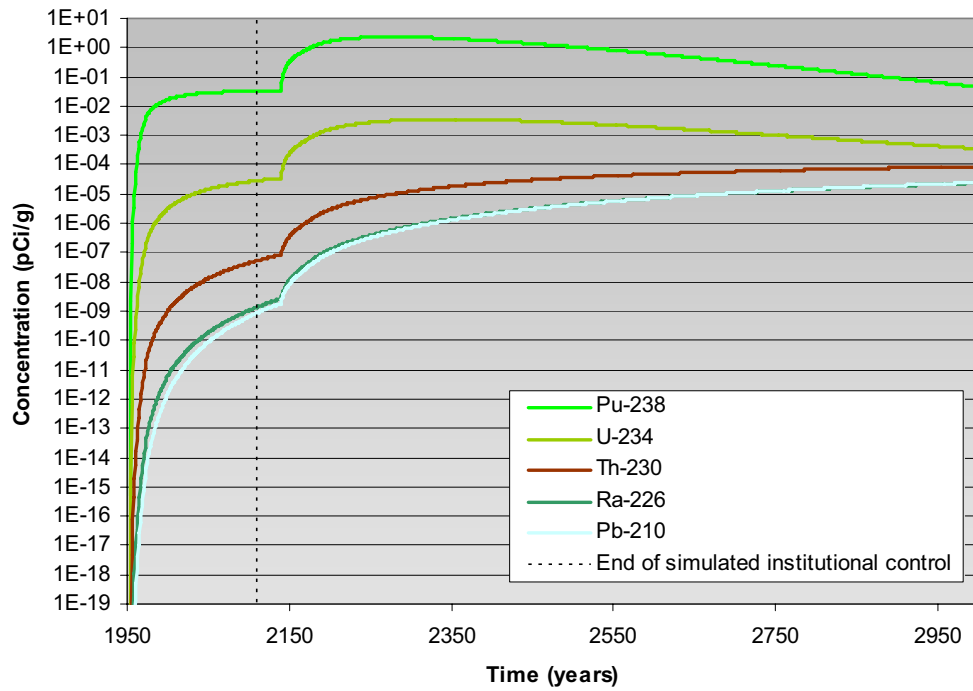
Figure 6-54. Simulated soil concentrations for Group 4 contaminants.
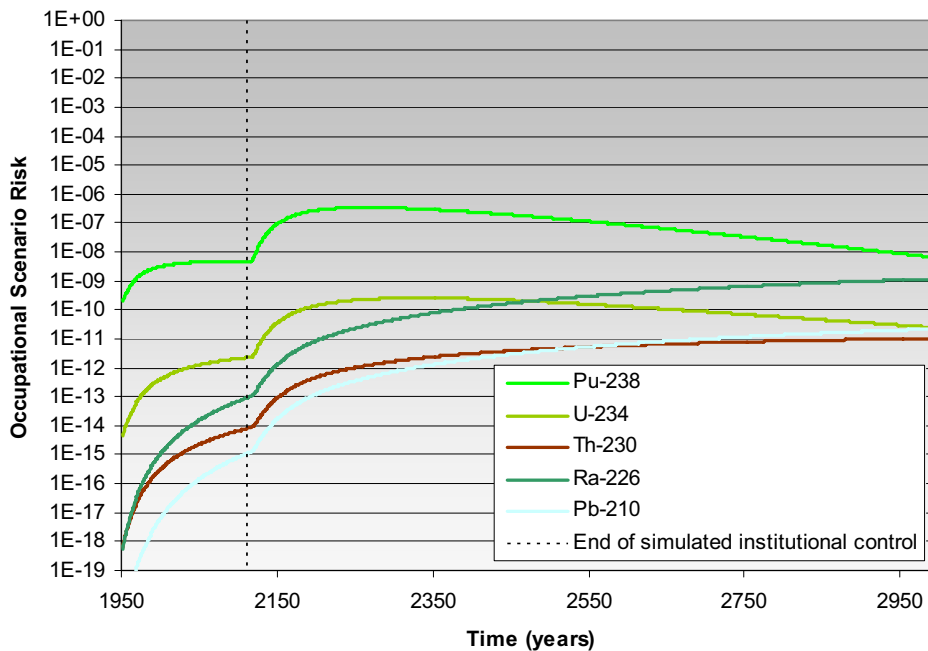
Figure 6-55. Simulated risk for the hypothetical future occupational scenario for Group 4 contaminants.

6.4.4.5   *Group 5 Contaminants.* This subsection provides simulated risk and concentration plots for Group 5 contaminants: U-238, U-234, Th-230, Ra-226, and Pb-210. Figures 6-56 through 6-62 present simulation results. Simulations in this section include disposal inventories for U-234, Th-230, Ra-226, and Pb-210. Contributions to total cumulative risks for U-234, Th-230, Ra-226, and Pb-210 also are included with Group 4 contaminants from decay of Pu-238, as indicated in the preceding section. Total risk comprises the highest risk from Ra-226 and Pb-210. These are from biotic uptake and surface exposure pathways. The risk plots show a large jump in the year 2110 because of the change in receptor location for the groundwater ingestion pathway and because surface exposure pathways are assumed to be viable after the hypothetical institutional control period. Primary groundwater ingestion risk comes from U-238 and U-234. The groundwater ingestion risk peak is 9E-05 for U-238 and 4E-05 for U-234. Groundwater ingestion risks are lower and later in time than risks presented in the ABRA because of the reduced mobility and solubility limit for uranium. Groundwater ingestion risk at the INL Site boundary peaks at less than 1E-06. Occupational risk shows a change in slope after the end of institutional control attributable to return to a native community; deeper rooting plants and larger burrowing animals increase uptake to the surface where the occupational receptor can be exposed.

6-83
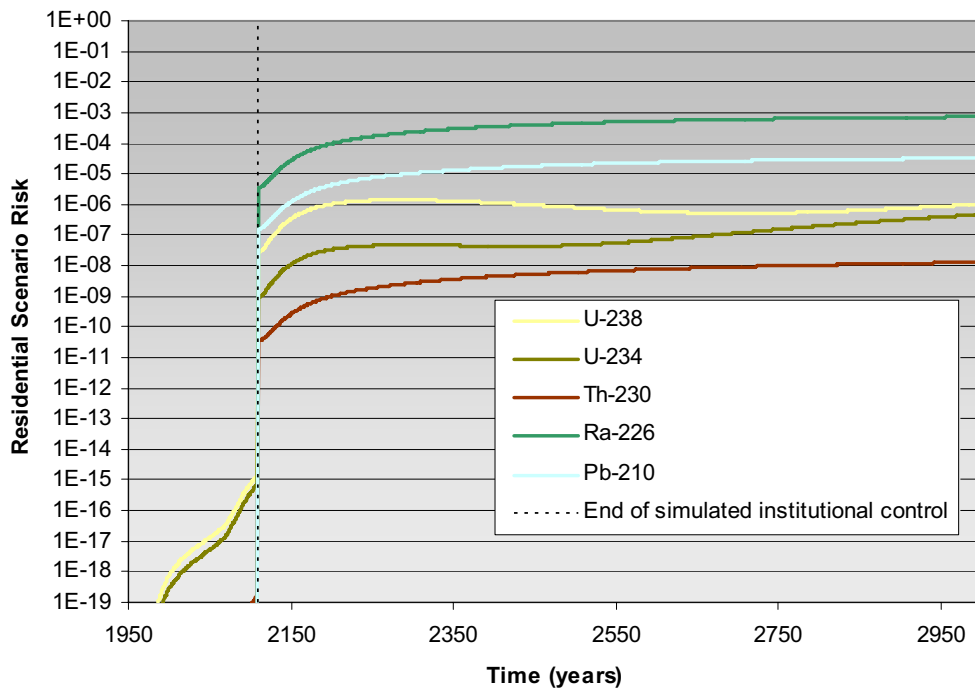
Figure 6-56. Total carcinogenic risk for Group 5 contaminants for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.
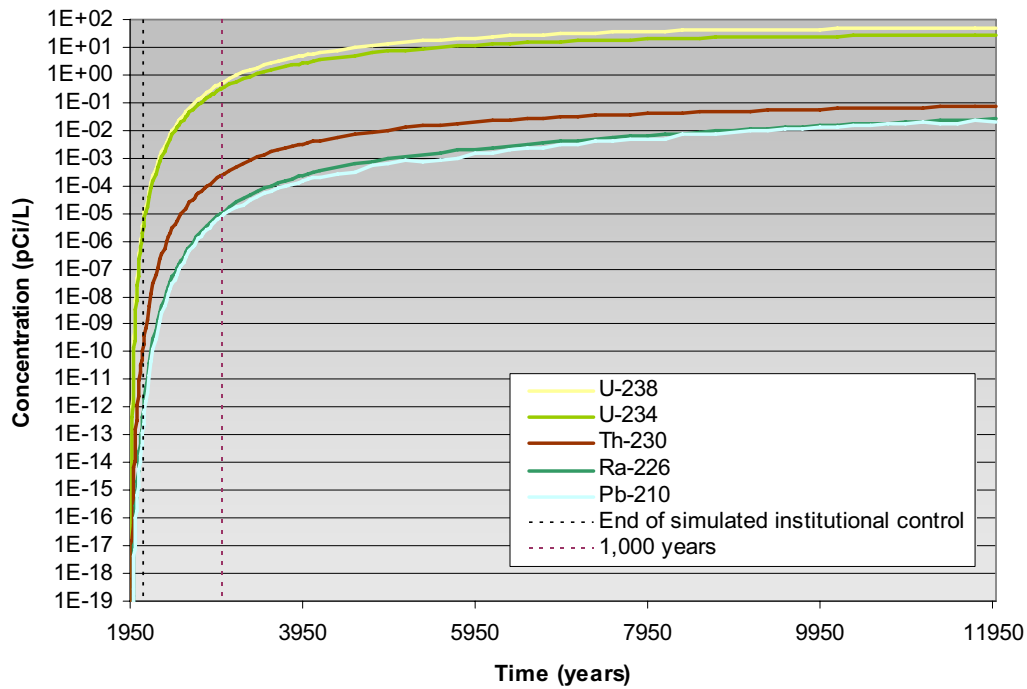
Figure 6-57. Simulated maximum groundwater concentrations for Group 5 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.
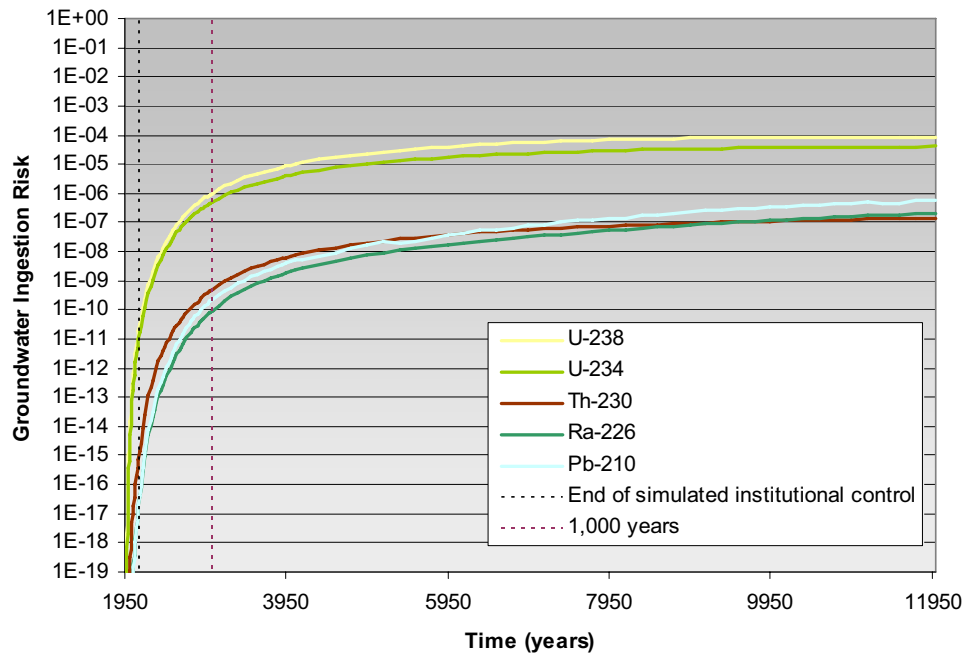
Figure 6-58. Groundwater ingestion risk at the Subsurface Disposal Area boundary for the 10,000-year simulation period for Group 5 contaminants.
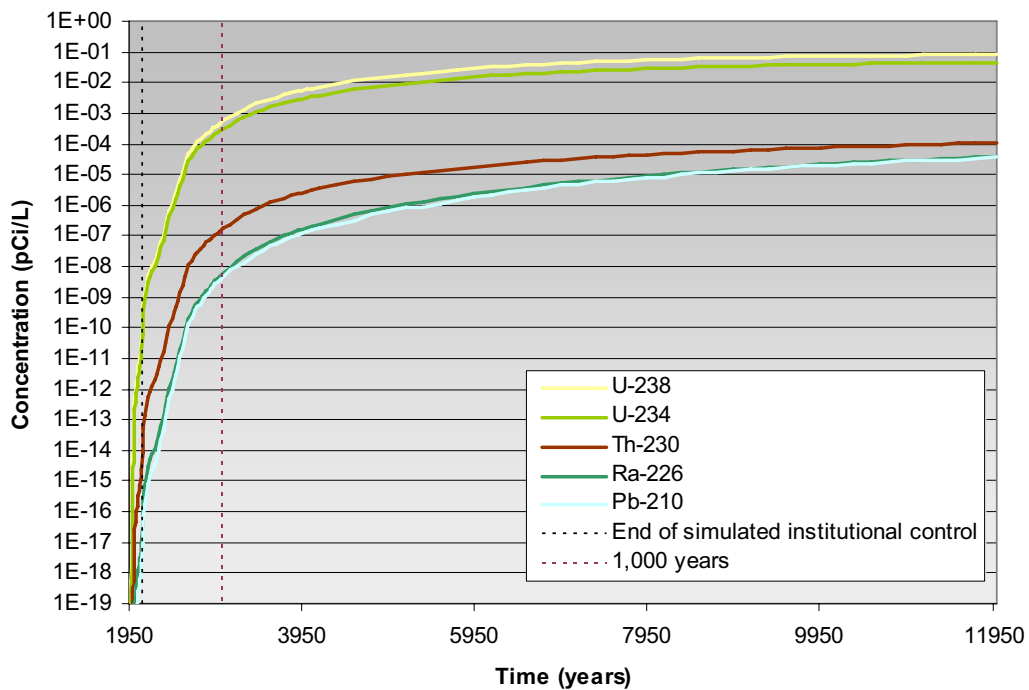
Figure 6-59. Simulated maximum groundwater concentrations for Group 5 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
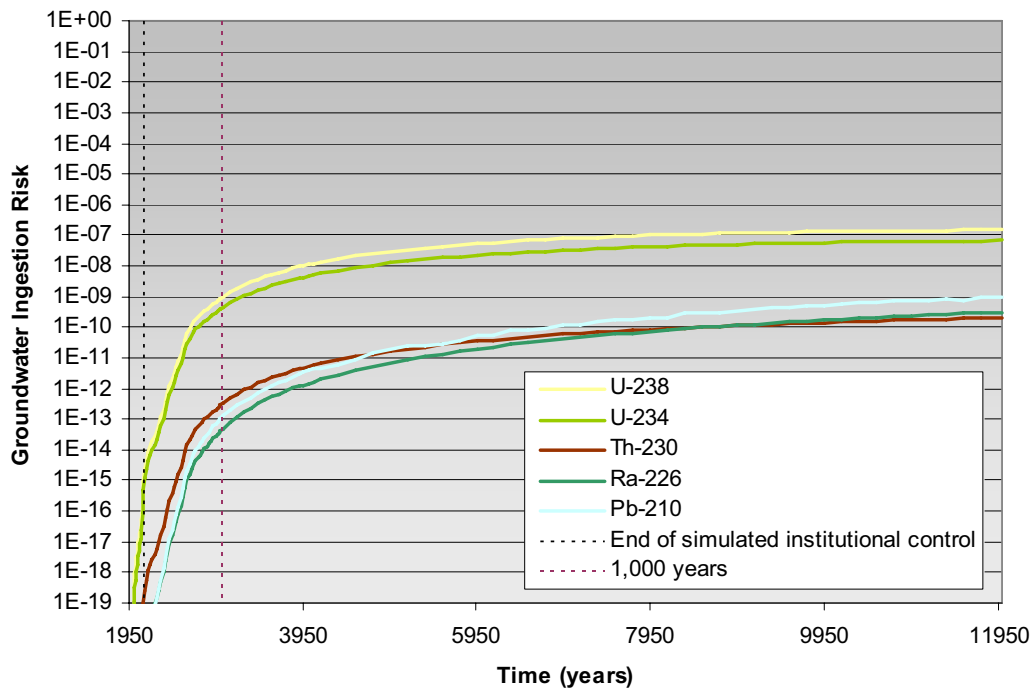
Figure 6-60. Simulated maximum groundwater ingestion risk for Group 5 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
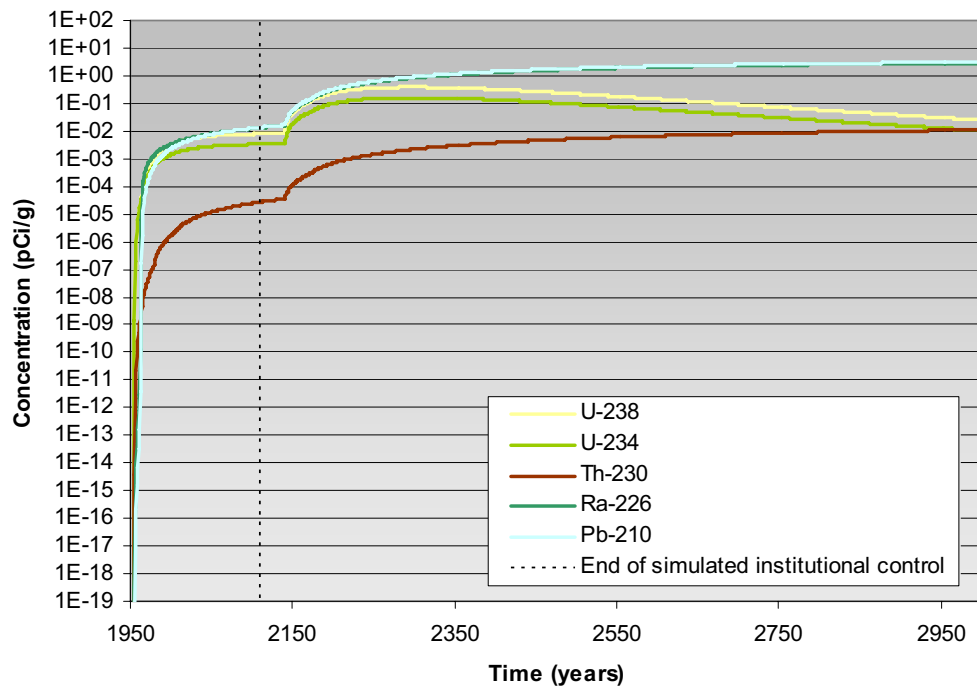
Figure 6-61. Simulated soil concentrations for Group 5 contaminants.
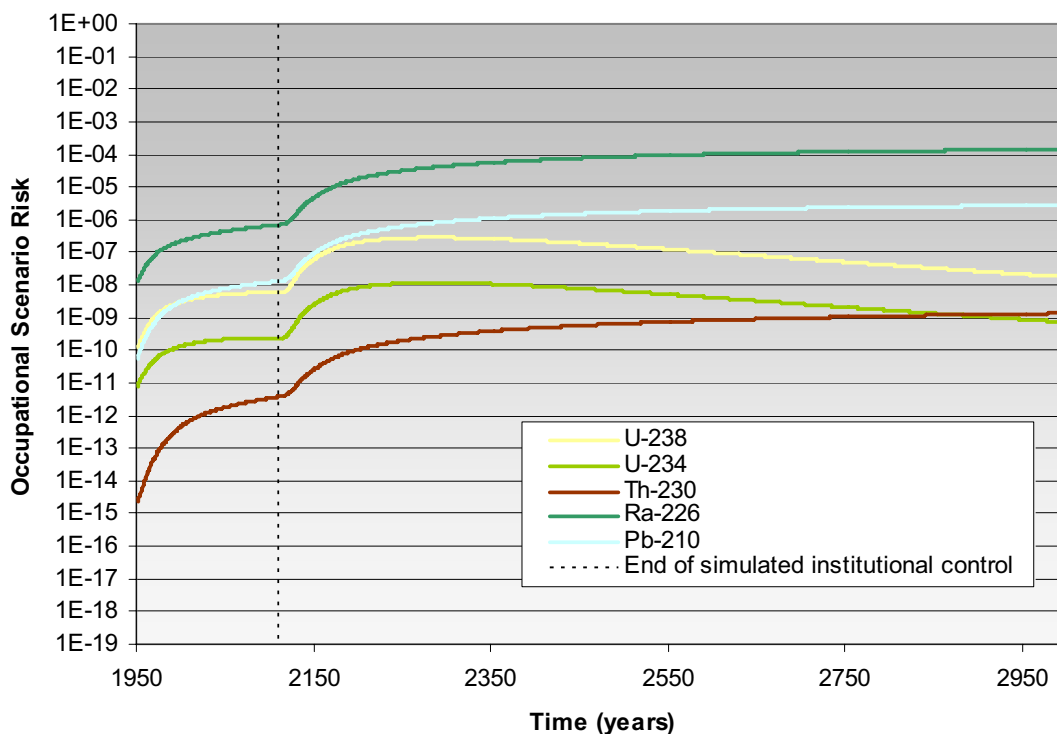
Figure 6-62. Occupational scenario risk for Group 5 contaminants for the 1,000-year simulation period.

6.4.4.6 **_Group 6 Contaminants._** This subsection provides simulated risk and concentration plots for Group 6 contaminants: Tc-99, I-129, and Cl-36. Isotopes in Group 6 are combined into one simulation for convenience, not because they are members of a single decay chain. Figures 6-63 through 6-69 present simulation results. Technetium-99 can be generated by activation or nuclear fission. Iodine-129 is primarily produced from fission. Chlorine-36 is primarily produced by activation. Table 5-2 provides information about major waste streams for each isotope. Unlike contaminants in Groups 1 through 5, Group 6 contaminants have multiple release mechanisms with multiple release rates (Anderson and Becker 2006). Total risk from each isotope is dominated by the groundwater ingestion pathway. Because these contaminants are mobile and conservative assumptions are made for release, risk peaks at the end of institutional control. However, measured concentrations are orders of magnitude below predicted concentrations (see Section 5.2.5.3.3). Therefore, risks shown are not representative for these contaminants. (See the recommendation in Section 7 to perform additional work in the feasibility study to develop risk estimates that better represent measured values and provide an improved basis for risk management decisions.)
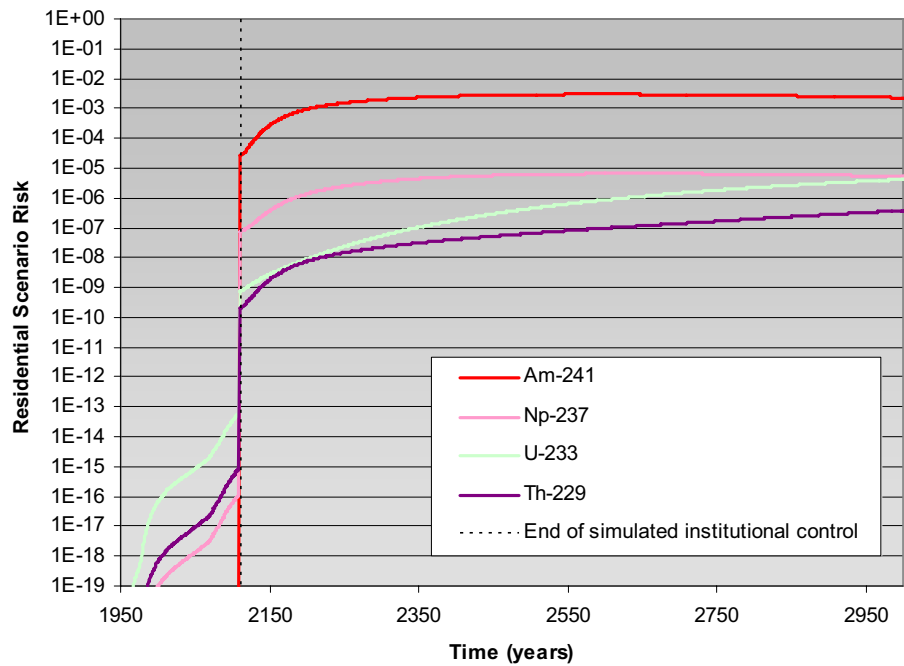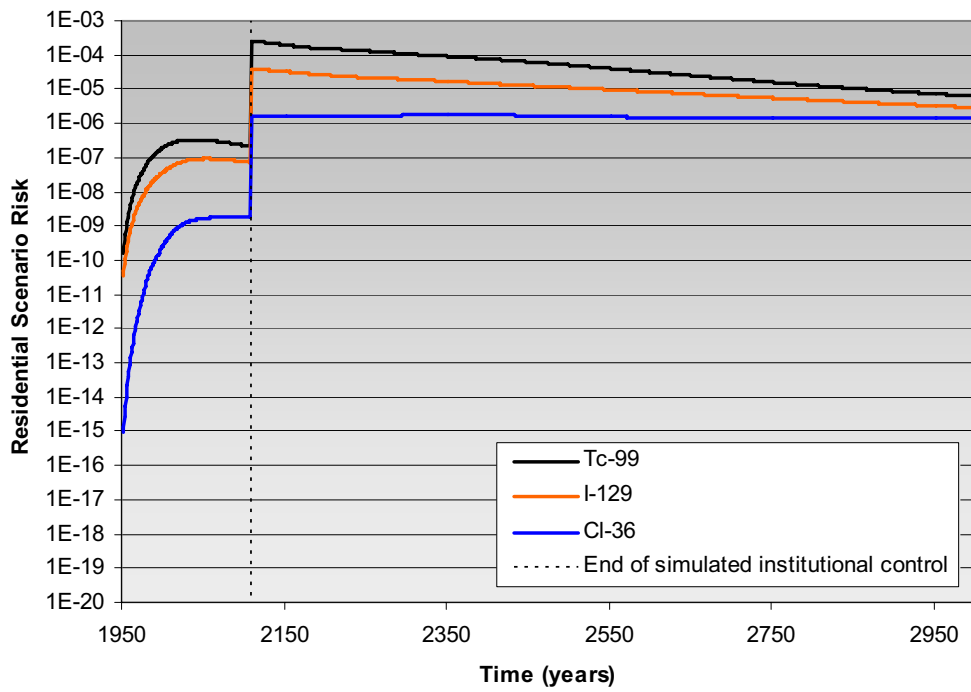
Figure 6-63. Total carcinogenic risk for Group 6 contaminants for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.
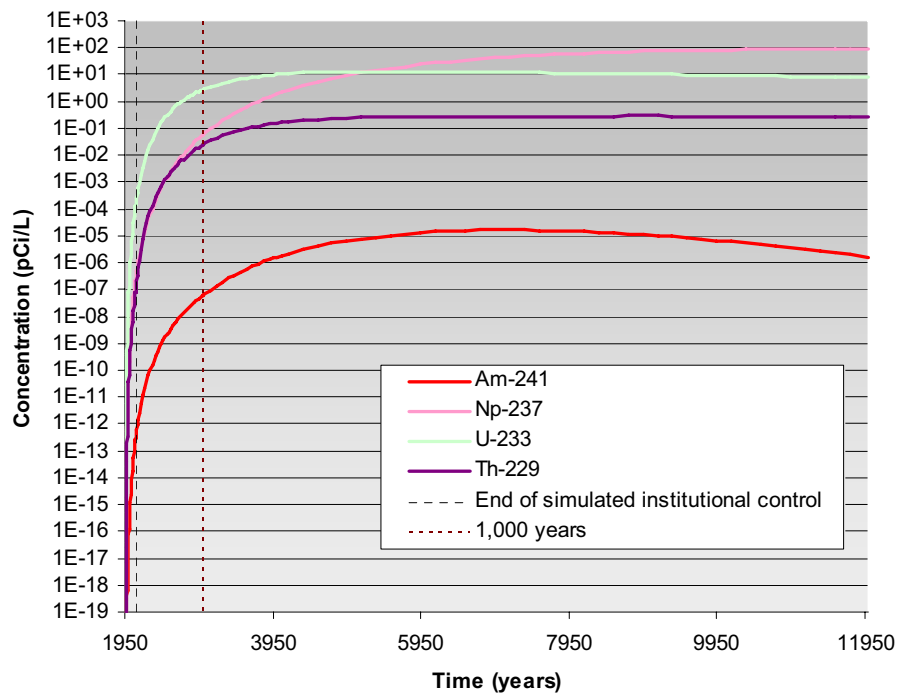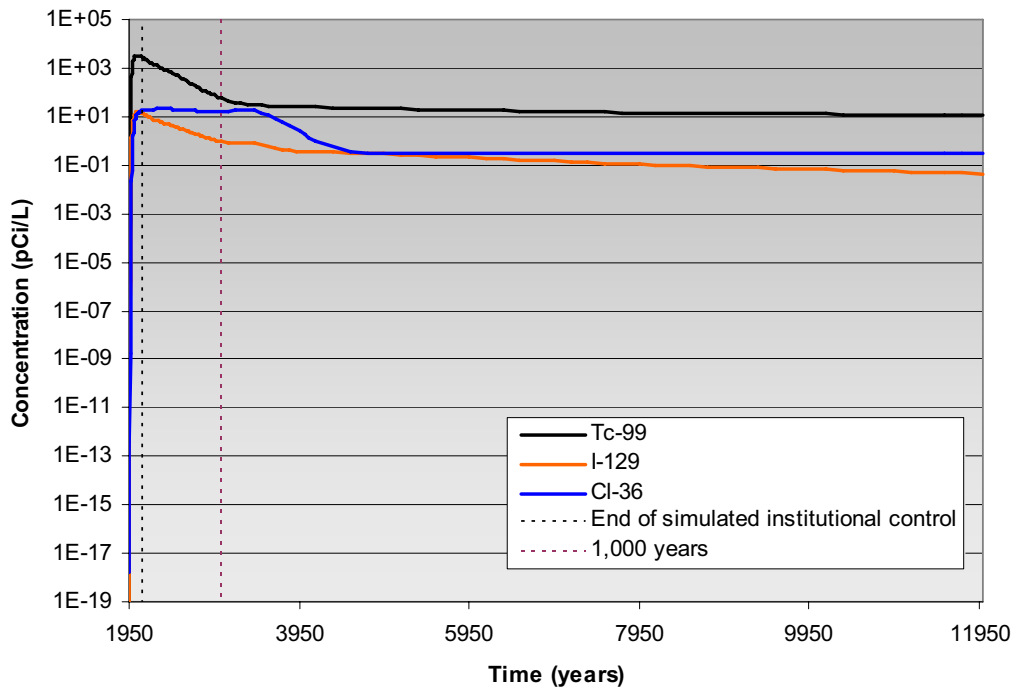

Figure 6-64. Simulated maximum groundwater concentrations for Group 6 contaminants at the Subsurface Disposal Area boundary for the 10,000-year simulation period.
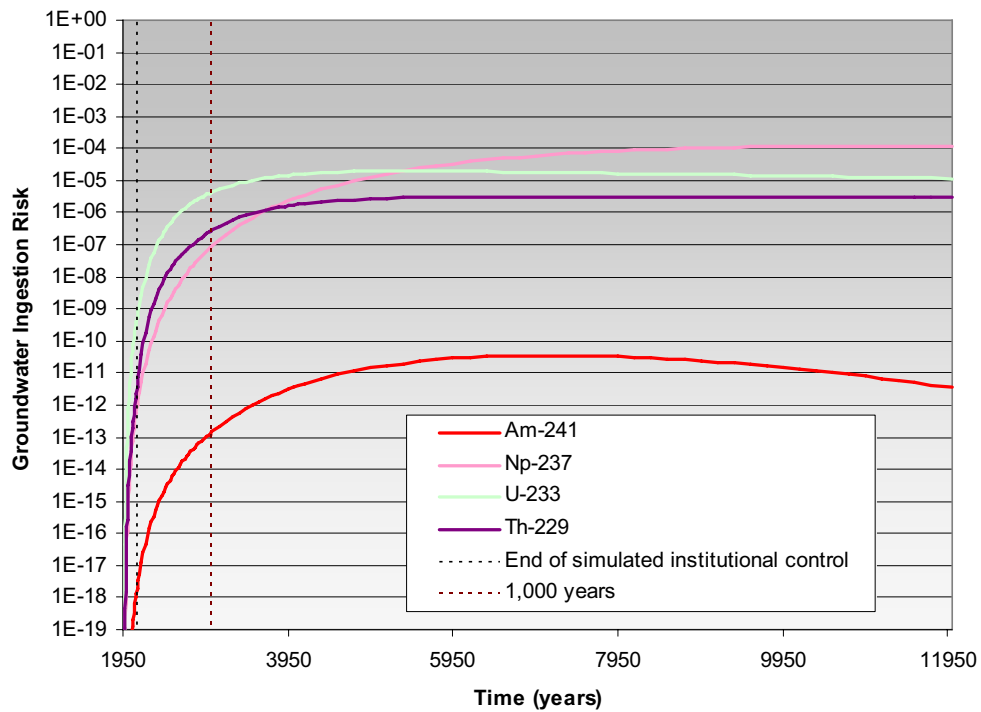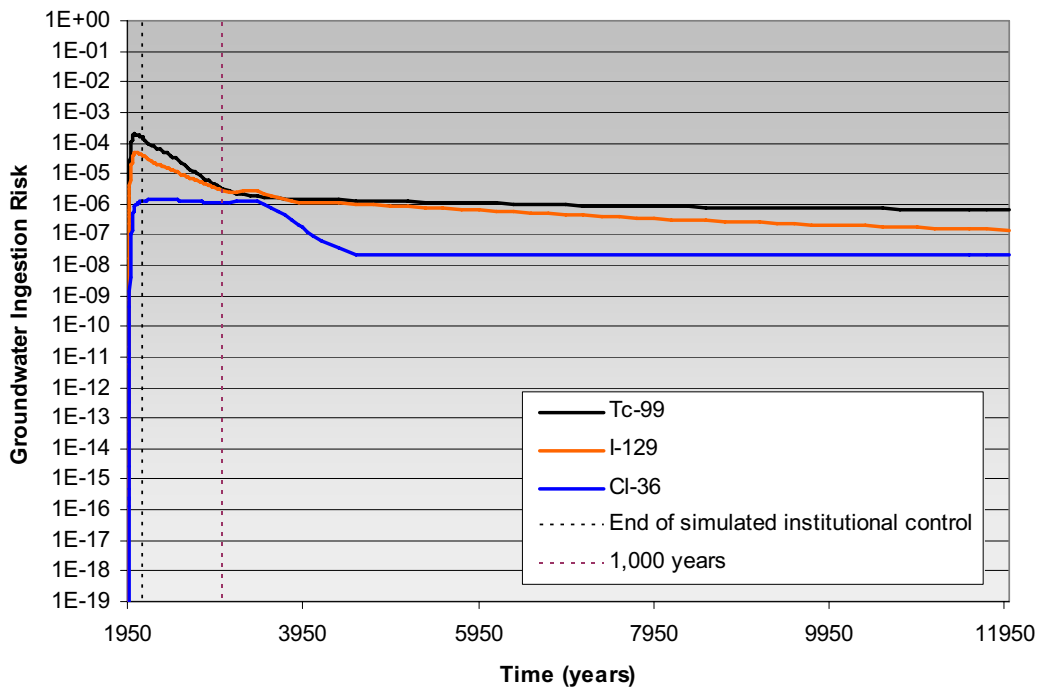
Figure 6-65. Groundwater ingestion risk at the Subsurface Disposal Area boundary for the 10,000-year simulation period for Group 6 contaminants.
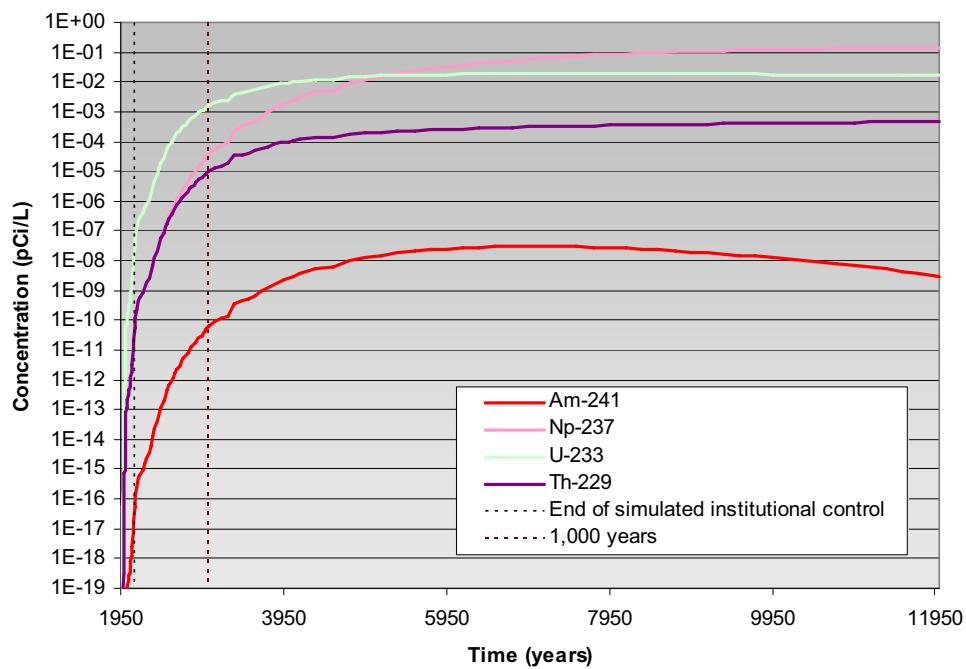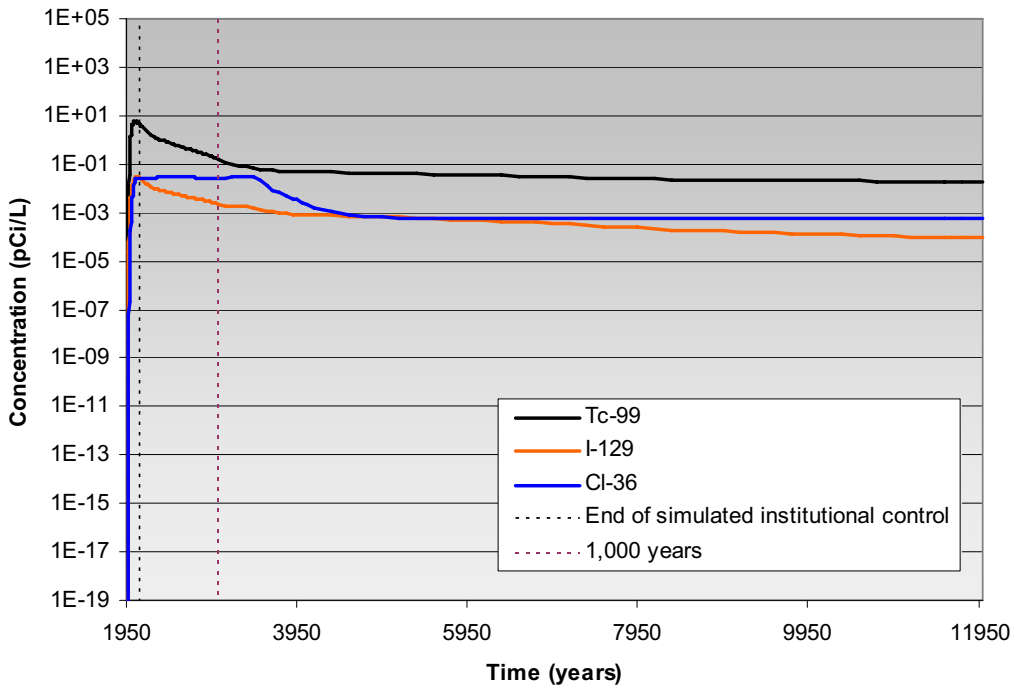

Figure 6-66. Simulated maximum groundwater concentrations for Group 6 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
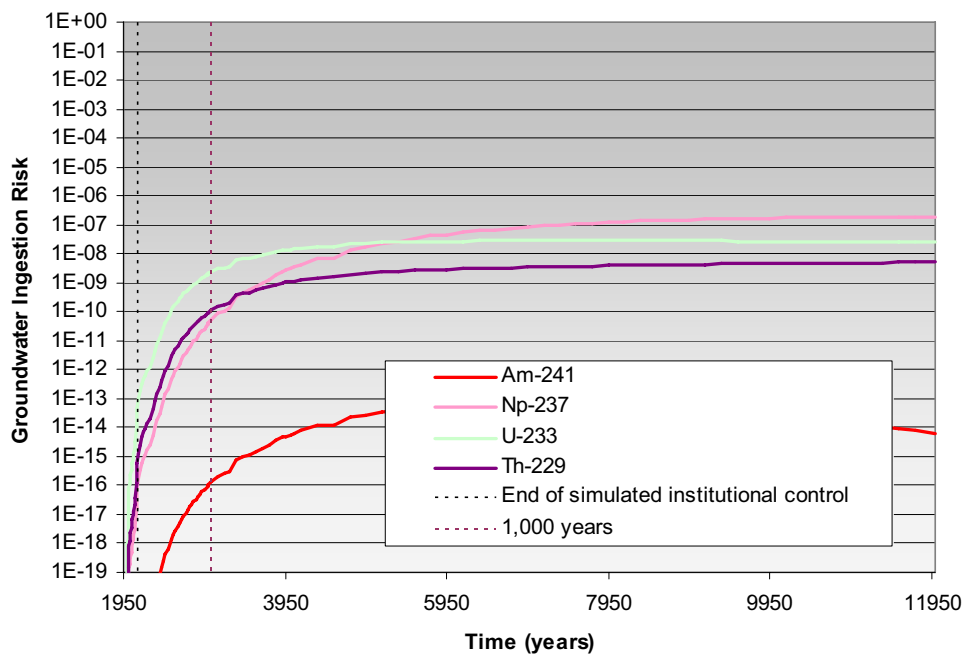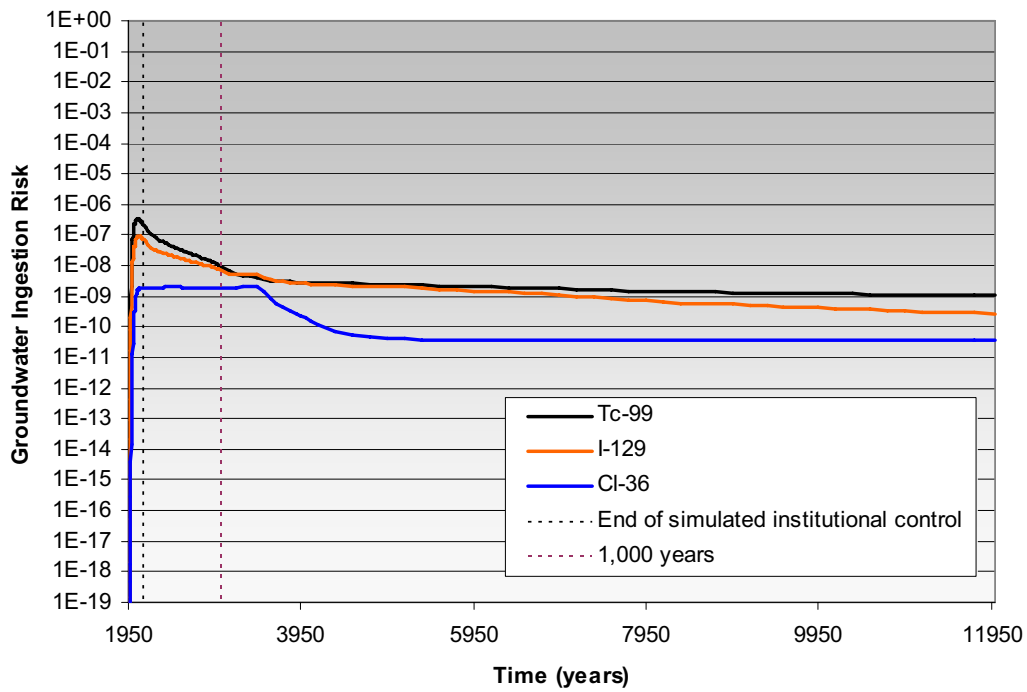
Figure 6-67. Simulated maximum groundwater ingestion risk for Group 6 contaminants at the southern boundary of the Idaho National Laboratory Site for the 10,000-year simulation period.
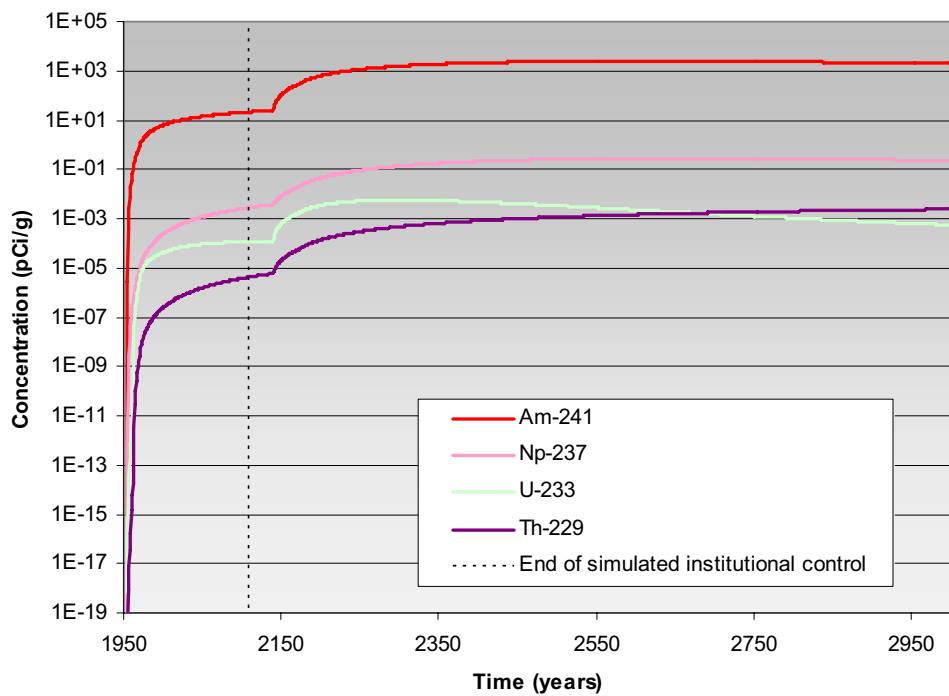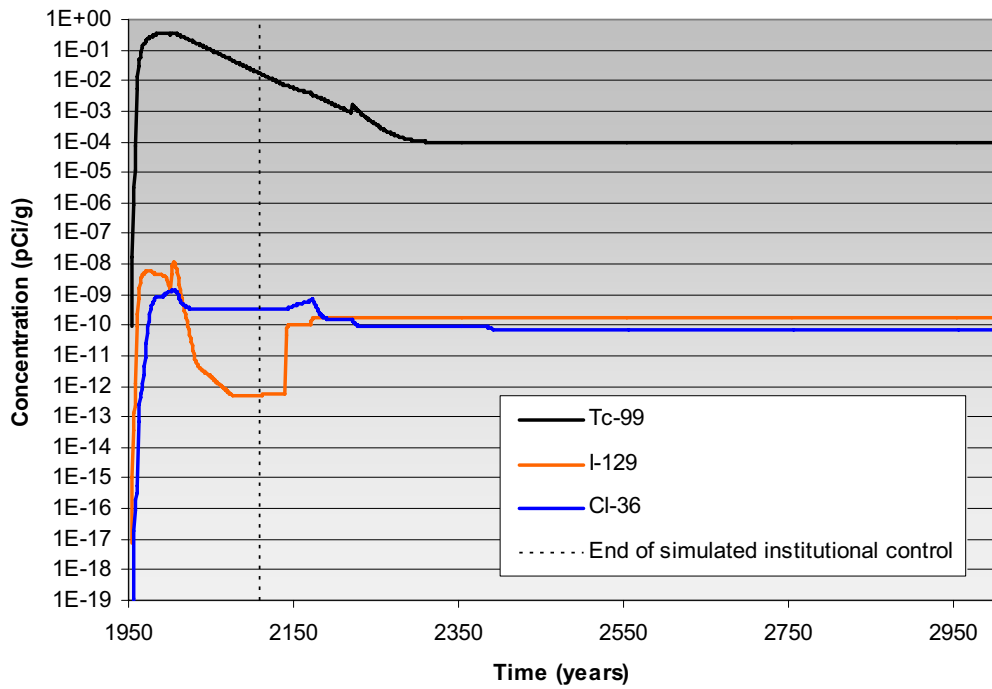

Figure 6-68. Simulated soil concentrations for Group 6 contaminants.
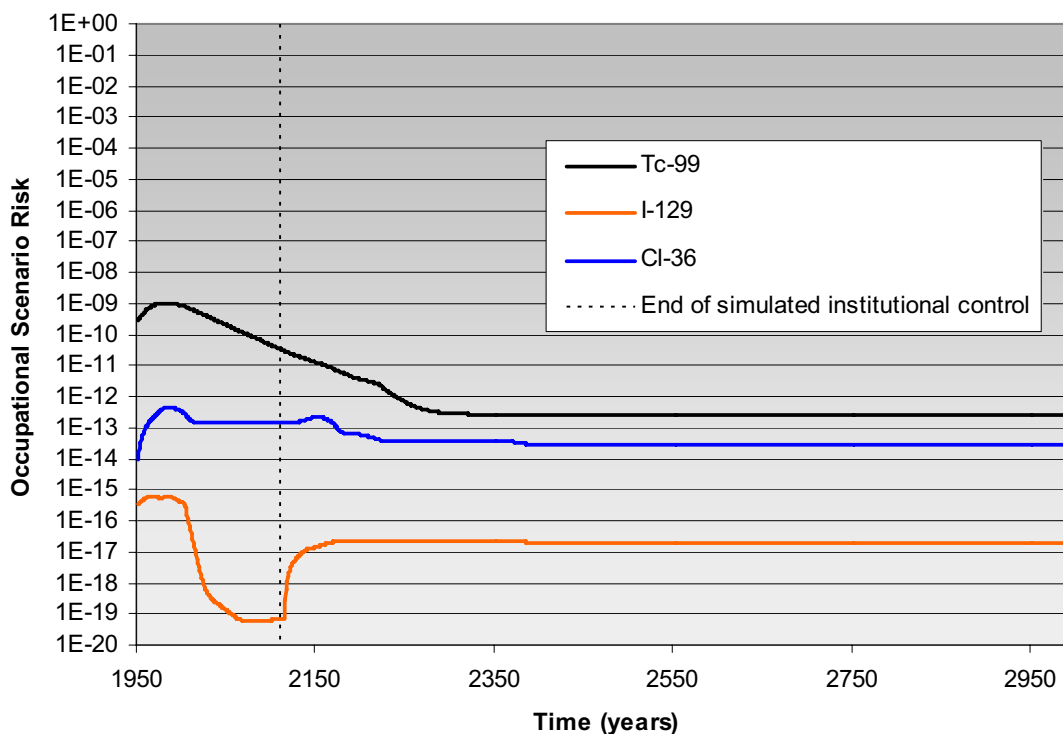
Figure 6-69. Occupational scenario risk for Group 6 contaminants for the 1,000-year simulation period.

6.4.4.7   *Group 8 Contaminant.* This subsection provides simulated risk and concentration plots for Group 8, which contains only one contaminant. Carbon-14 is simulated in its own group because it is the only radioisotope that partitions into the vapor phase and can be transported to the aquifer through gaseous diffusion. Figures 6-70 through 6-75 present simulation results. Carbon-14 is generated from activation of nitrogen in a reactor. Much of the C-14 is contained in metal and has a relatively slow release; however, a small fraction of the C-14 is in resins or other releasable waste forms (see Table 5-2). Total risk is dominated by the groundwater ingestion pathway, with a minor contribution from inhalation of volatiles. Risk peaks at the end of institutional control as a result of initial release and because C-14 is very mobile as a vapor. The long-term risk is driven by slow release from activated metal.
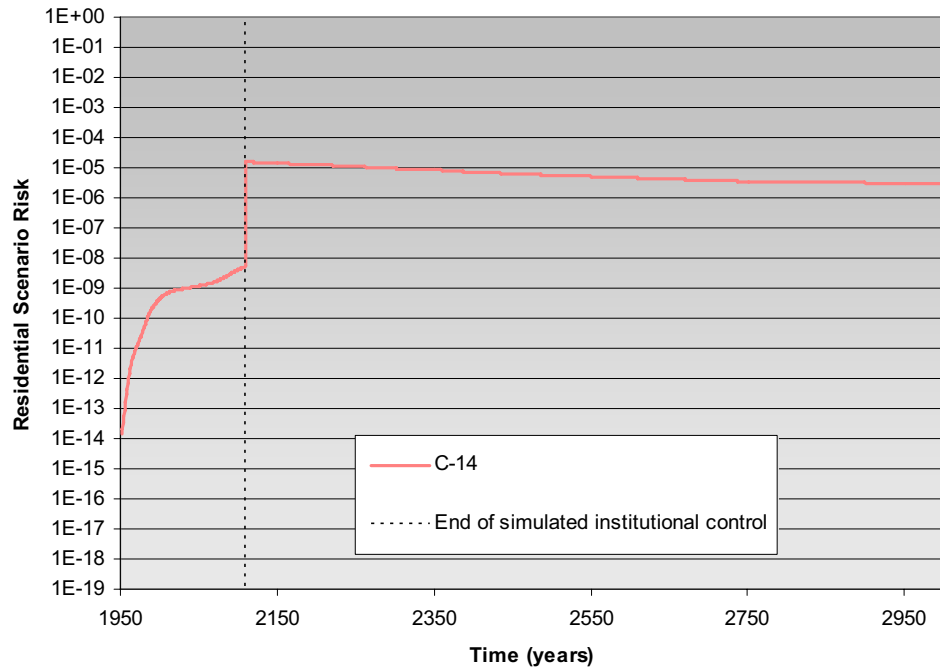
Figure 6-70. Total carcinogenic risk for Group 8 contaminant for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.
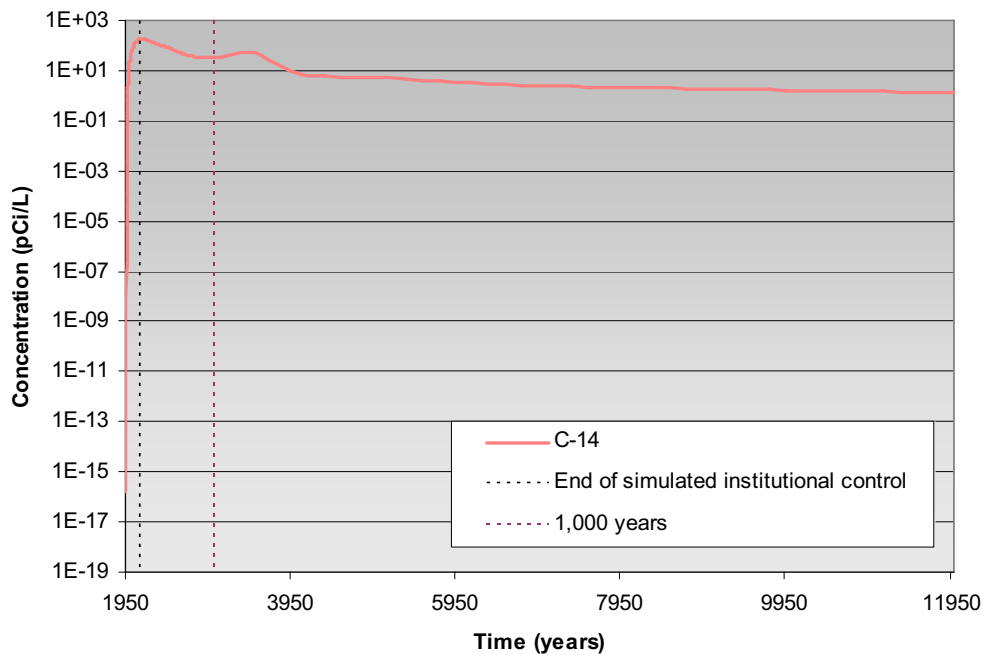
Figure 6-71. Simulated maximum groundwater concentrations for Group 8 contaminant at the Subsurface Disposal Area boundary over 10,000 years.
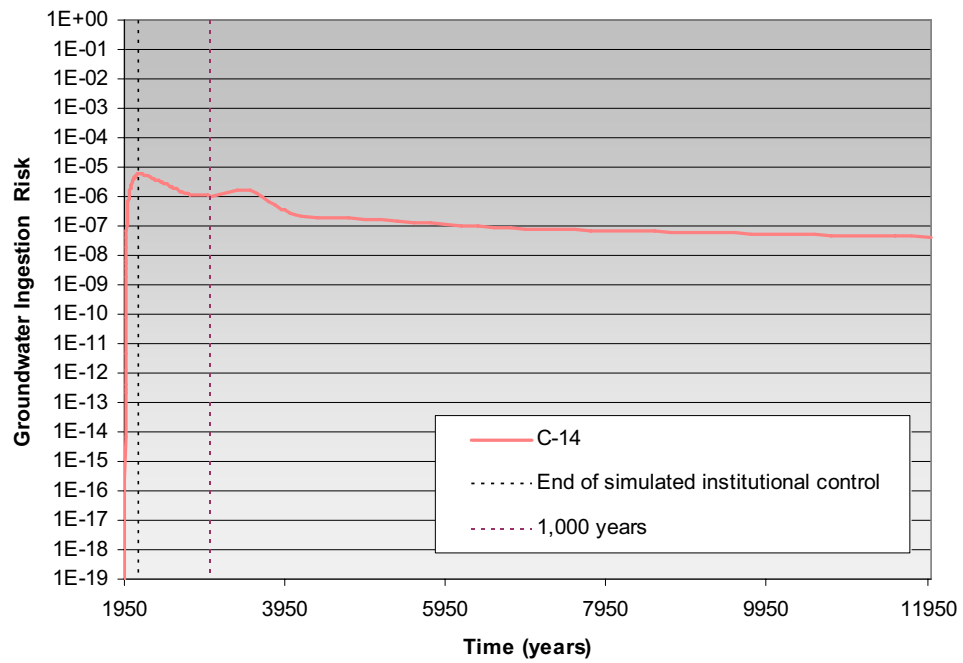
Figure 6-72. Groundwater ingestion risk for the 10,000-year simulation period for Group 8 contaminant.
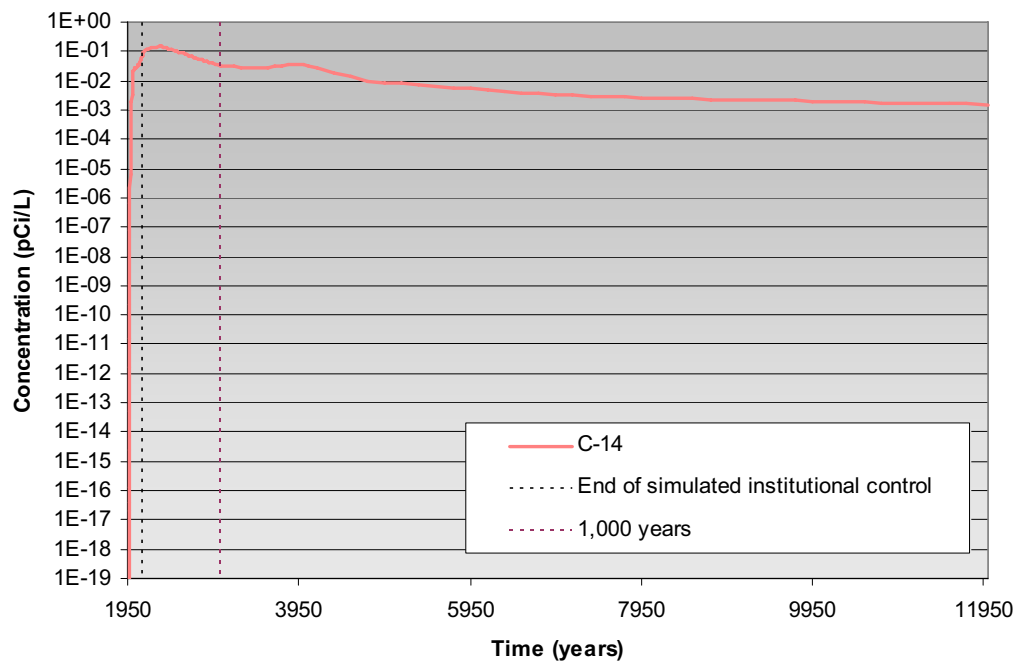
Figure 6-73. Simulated maximum groundwater concentrations for Group 8 contaminant over 10,000 years at the southern boundary of the Idaho National Laboratory Site.
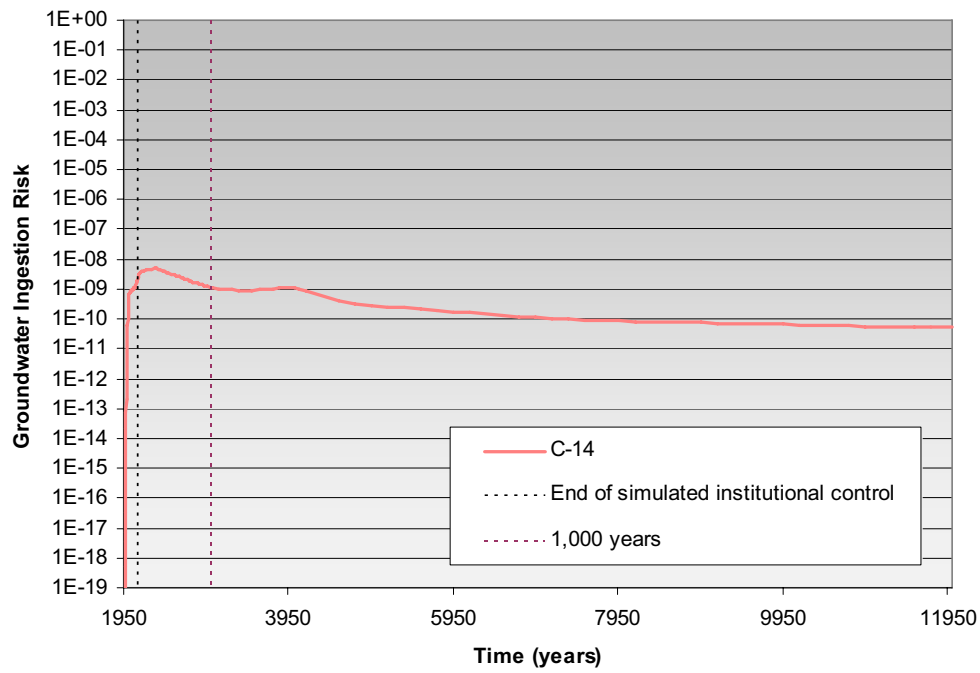
Figure 6-74. Simulated maximum groundwater ingestion risk for Group 8 contaminant over 10,000 years at the southern boundary of the Idaho National Laboratory Site.
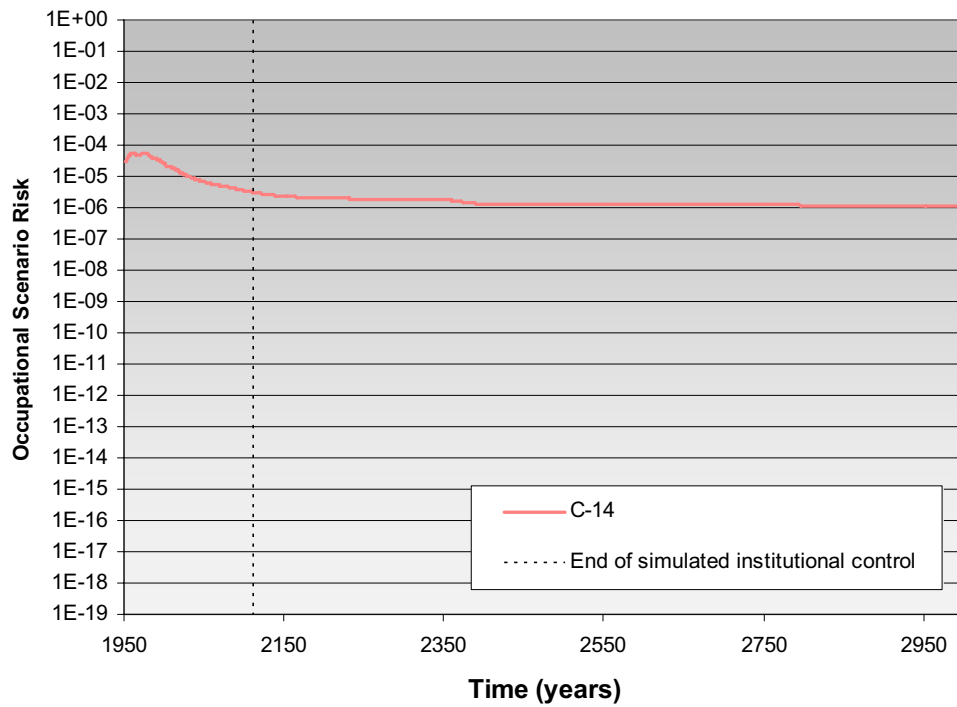
Figure 6-75. Simulated occupational scenario risk for the Group 8 contaminant.

6.4.4.8   Group 9 Contaminants. This subsection provides simulated risk and concentration plots for Group 9 contaminants (i.e., Cs-137, Nb-94, Sr-90, and Th-228). Figures 6-76 through 6-78 present simulation results. Group 9 contaminants were evaluated for surface exposure pathways only. Based on results from the ABRA, groundwater pathways were eliminated from evaluation (i.e., groundwater risks were very low). Therefore, groundwater concentrations and risk plots are not presented. Because groundwater risks are not computed, no risk is presented before the end of institutional control in the year 2110. Cesium-137 and Sr-90 risks peak early at 2E-03 and 1E-03, respectively, and decline rapidly because of radioactive decay. Niobium-94 risk peaks later but remains less than 1E-05. Thorium-228 risk peaks at the end of the 1,000-year simulation period due to ingrowth.
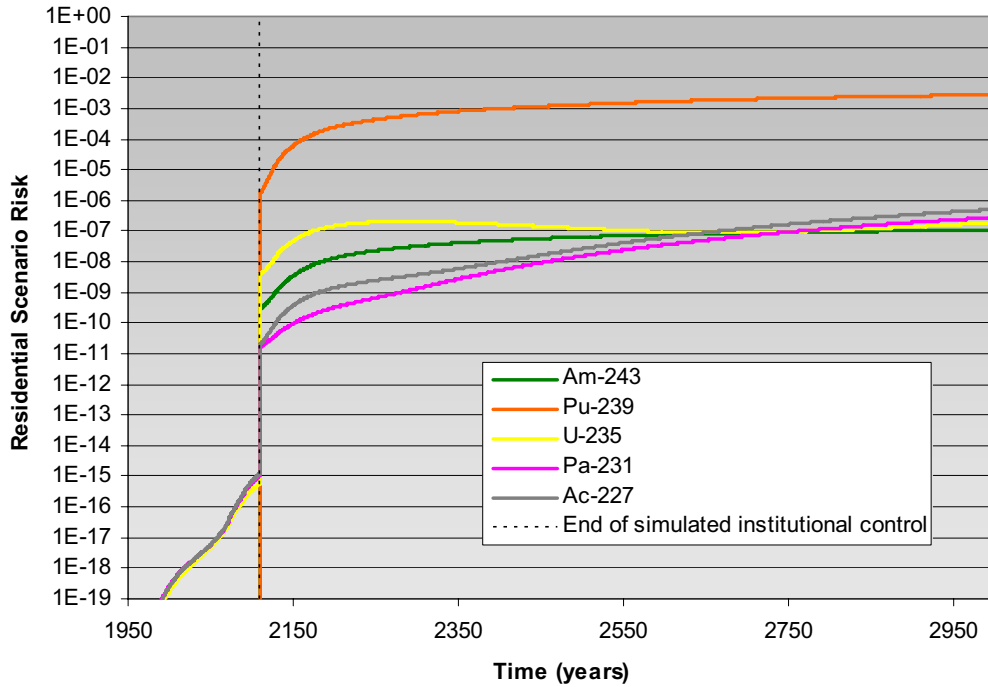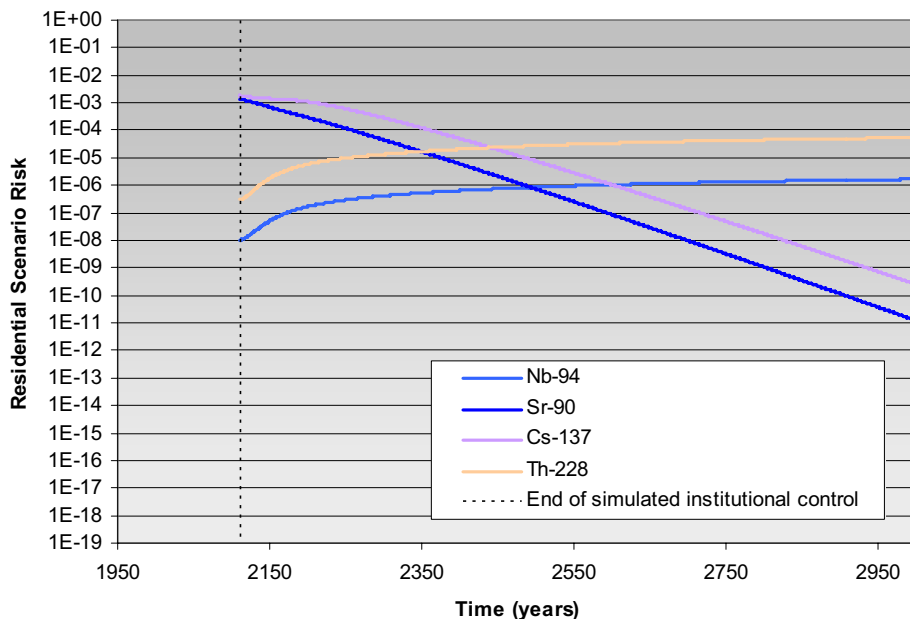

Figure 6-76. Total carcinogenic risk for Group 9 contaminants for hypothetical future residential exposure pathways for the 1,000-year simulation period.
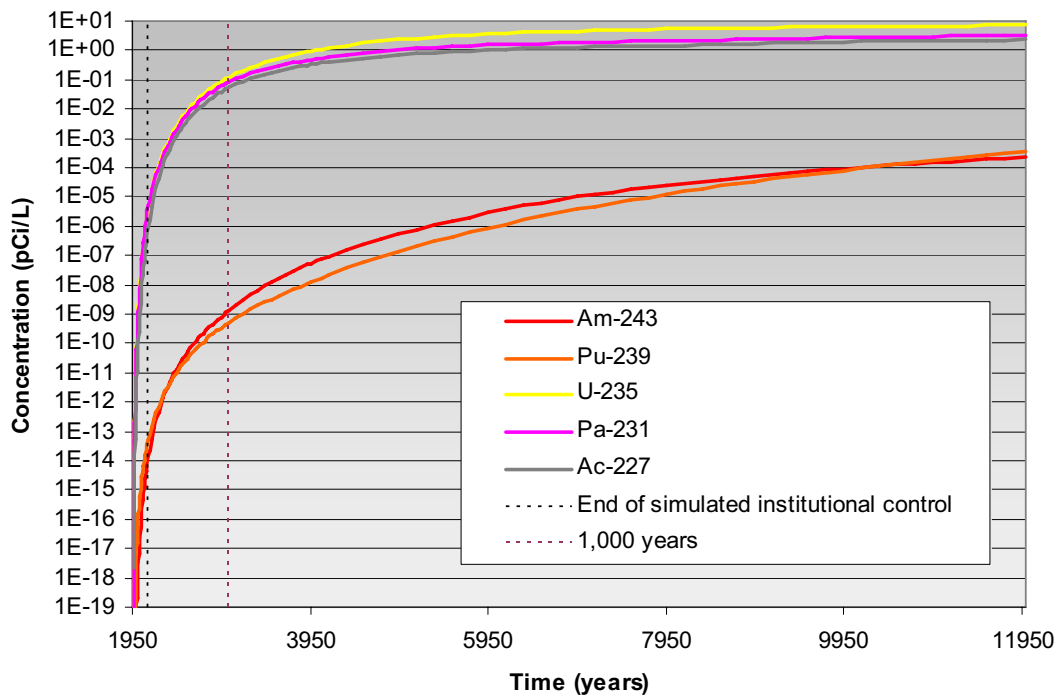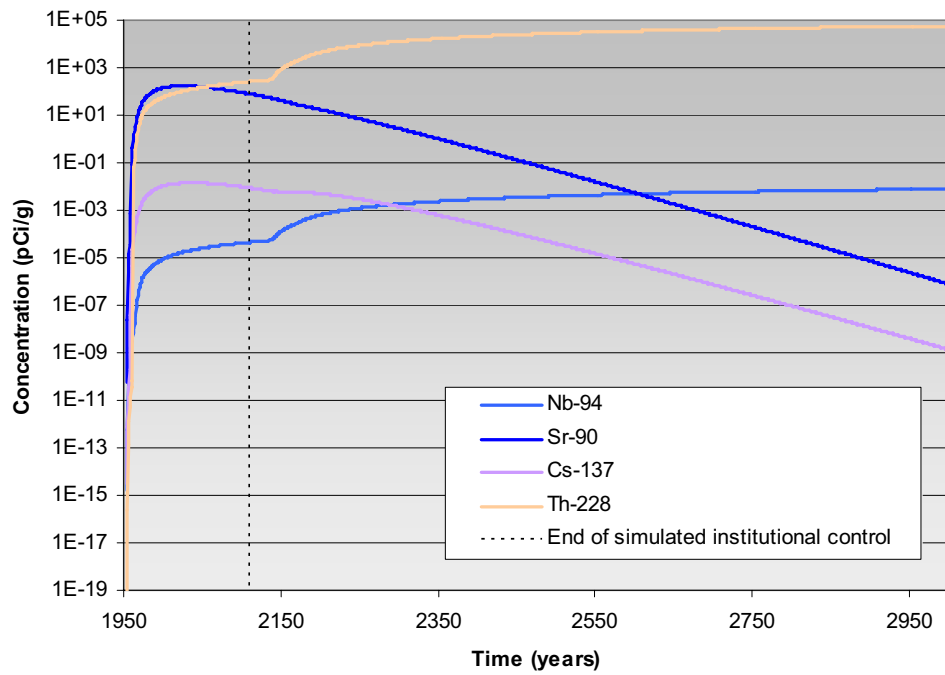
Figure 6-77. Simulated soil concentrations for Group 9 contaminants.
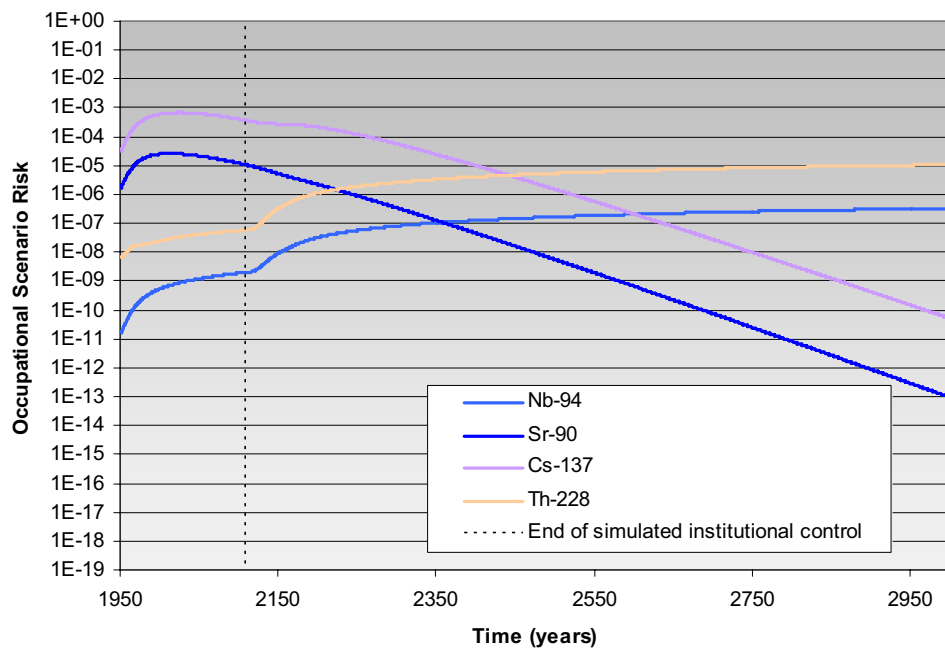
Figure 6-78. Simulated occupational scenario risk for Group 9 contaminants.

6.4.4.9   Group 10 Contaminant. This subsection provides the simulated hazard index and concentration plots for the Group 10 contaminant, nitrate. Figures 6-79 through 6-84 present simulation results. The nitrate hazard index reaches 1 at the end of institutional control. Nitrate is mobile and moves with soil water. The only limit on release is the assumed drum-failure model, which retrievals by the Operable Unit 7-10 Glovebox Excavator Method and Accelerated Retrieval projects show is conservative. Predicted concentrations also exceed the nitrate MCL. Because groundwater ingestion is not a complete exposure pathway for occupational scenarios, the hazard index for the occupational scenario peaks below 1E-07.
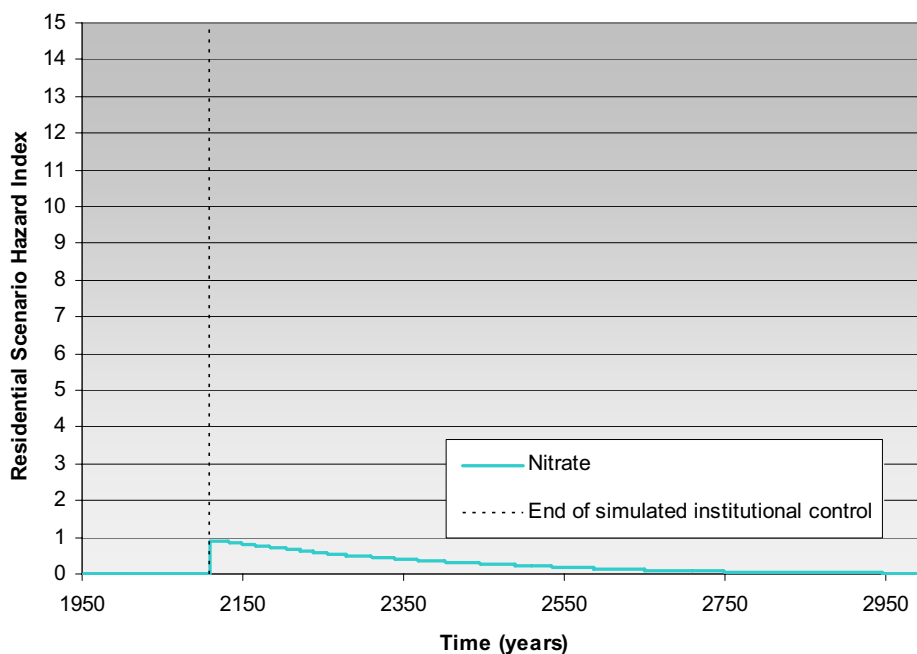
Figure 6-79. Total hazard index for the Group 10 contaminant for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.
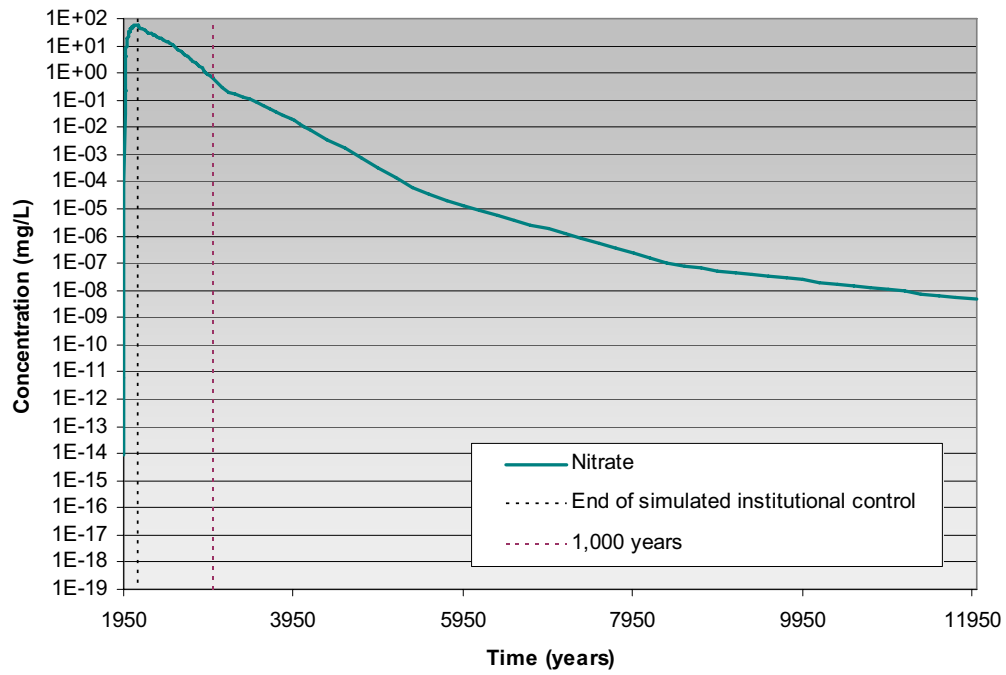
Figure 6-80. Simulated maximum groundwater concentrations at the Subsurface Disposal Area boundary for Group 10 contaminant over 10,000 years.
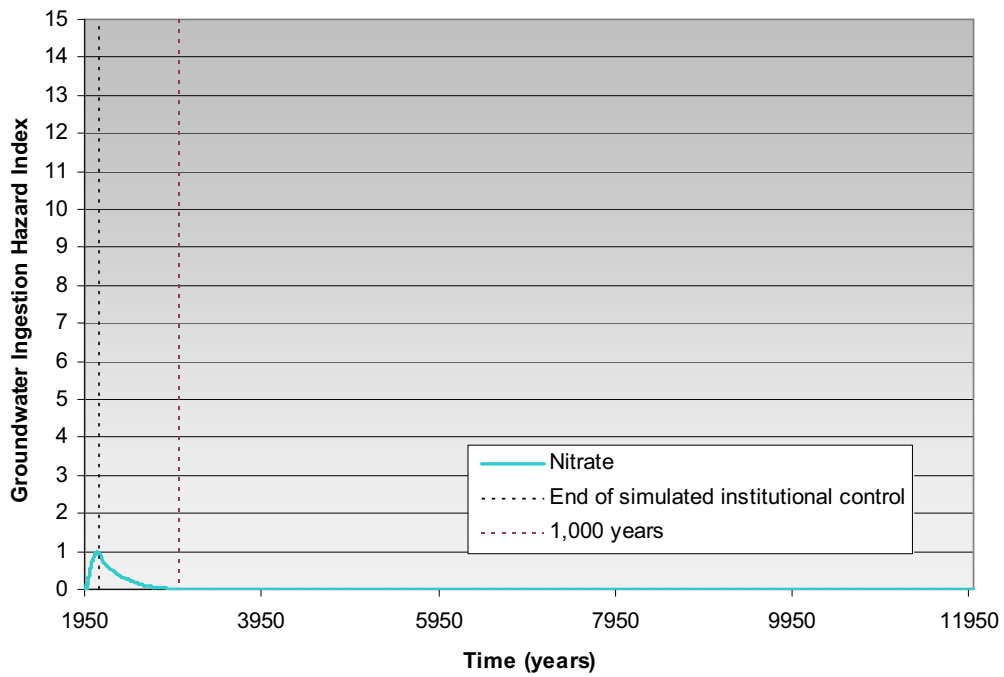
Figure 6-81. Groundwater ingestion hazard index at the Subsurface Disposal Area boundary for Group 10 contaminant for the 10,000-year simulation period.
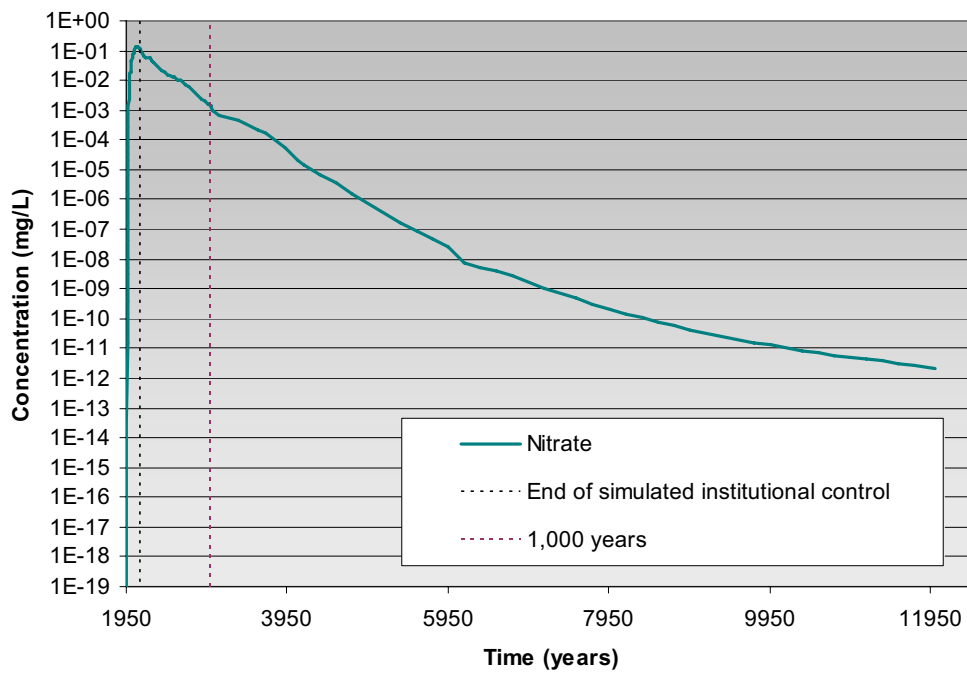
Figure 6-82. Simulated maximum groundwater concentrations for Group 10 contaminant over 10,000 years at the southern boundary of the Idaho National Laboratory Site.
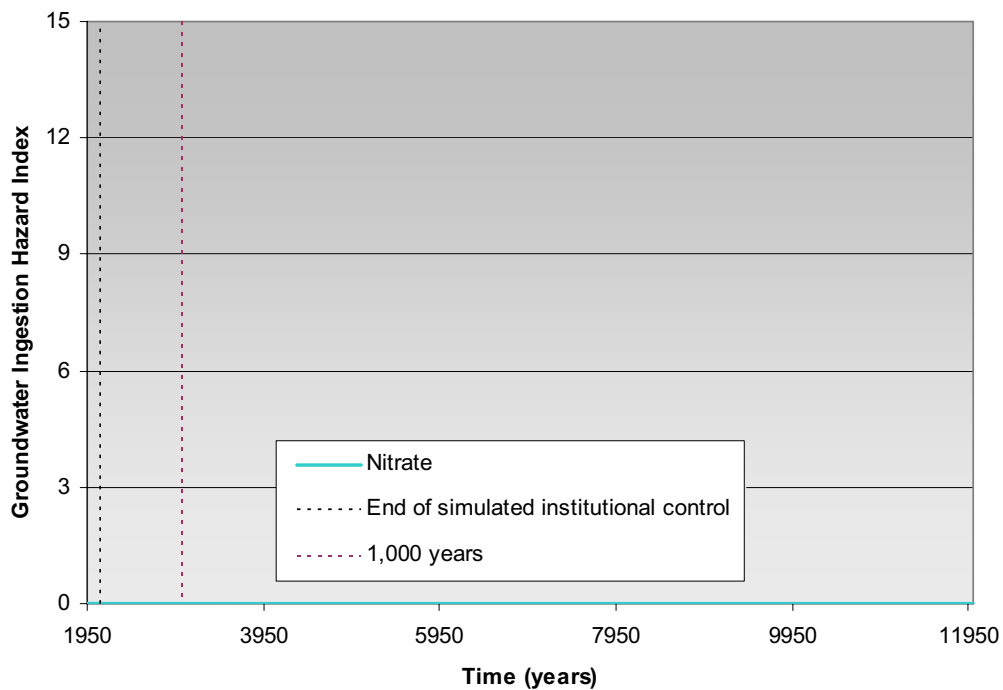
Figure 6-83. Simulated maximum groundwater ingestion hazard index for Group 10 contaminant over 10,000 years at the southern boundary of the Idaho National Laboratory Site.
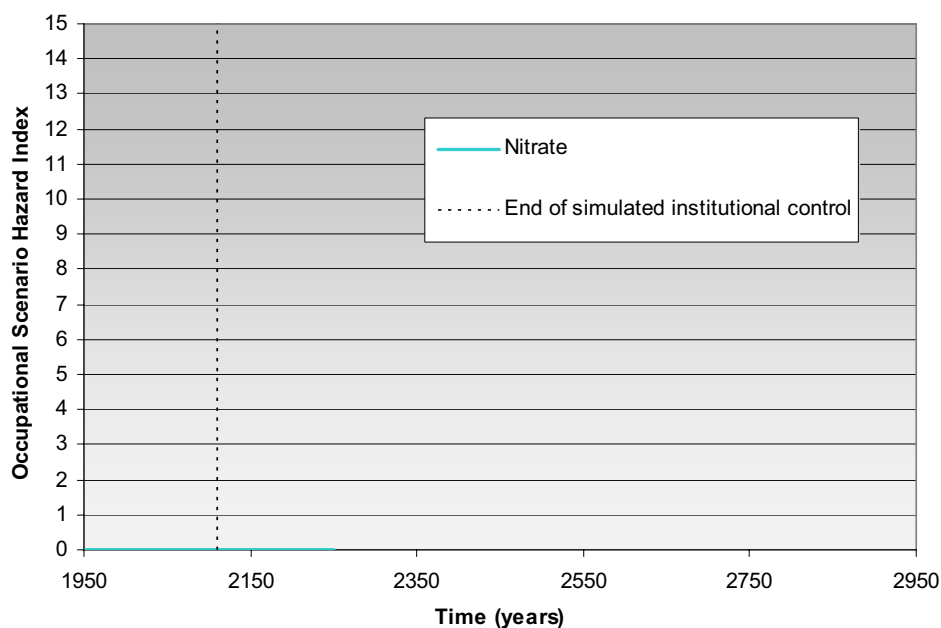
Figure 6-84. Simulated occupational scenario hazard index for Group 10 contaminant.

6.4.4.10   Group 11 Contaminants. This subsection provides simulated risk, hazard index, and concentration plots for Group 11 contaminants (i.e., carbon tetrachloride, 1,4-dioxane, methylene chloride, and tetrachloroethylene). Figures 6-85 through 6-94 present simulation results. All four contaminants are VOCs. Release is controlled by assumed container failure and diffusion from organic sludge buried in the SDA. Base-case simulations have OCVZ operations continuing through the year 2009.
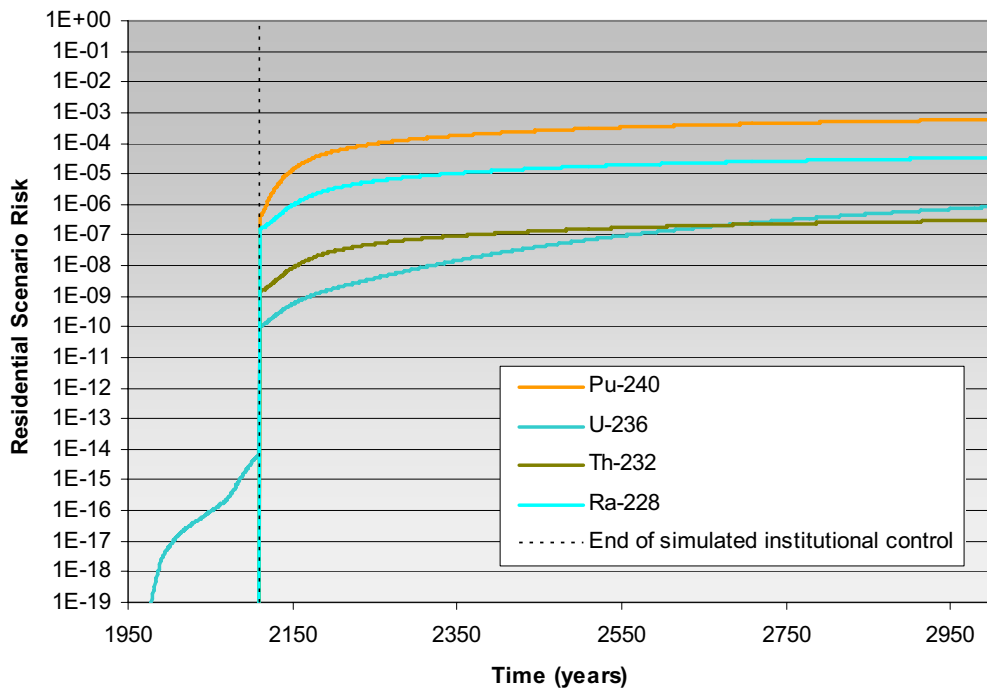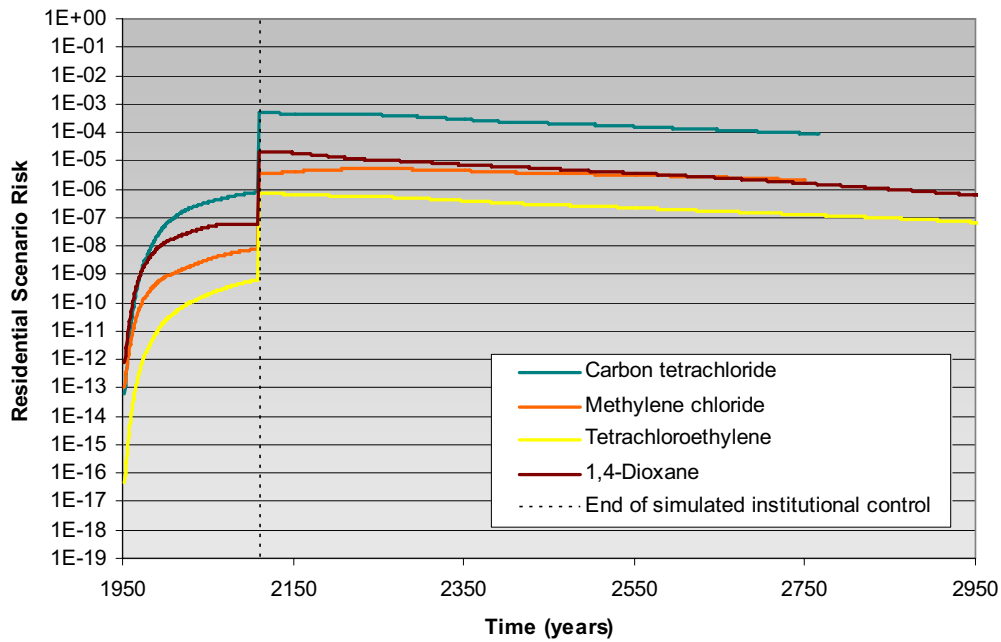
Figure 6-85. Total carcinogenic risk for Group 11 contaminants for hypothetical future residential exposure pathways for the 1,000-year simulation period.
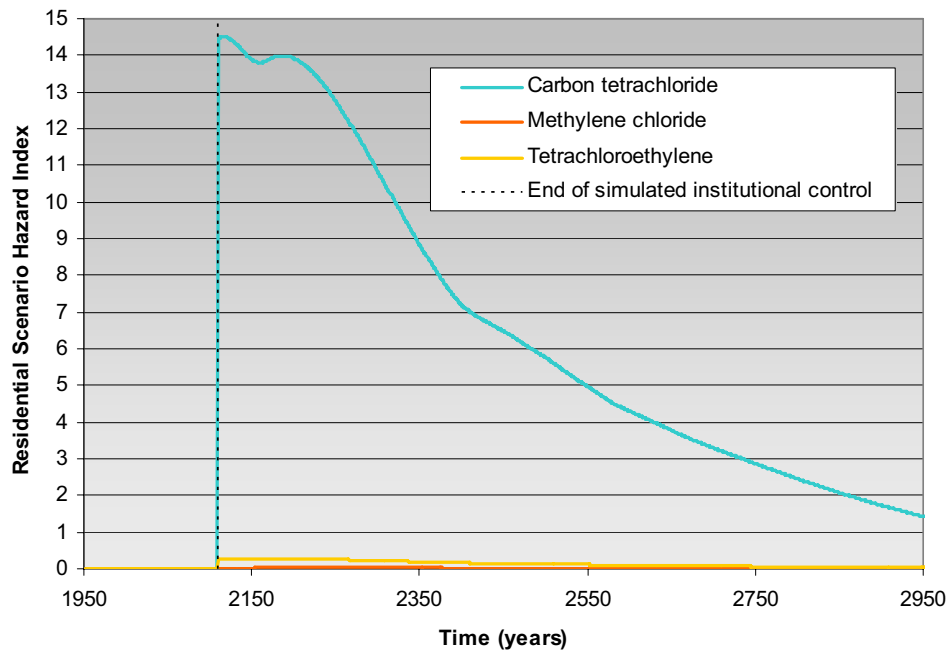
Figure 6-86. Total hazard index for Group 11 contaminants for hypothetical future residential scenario exposure pathways for the 1,000-year simulation period.
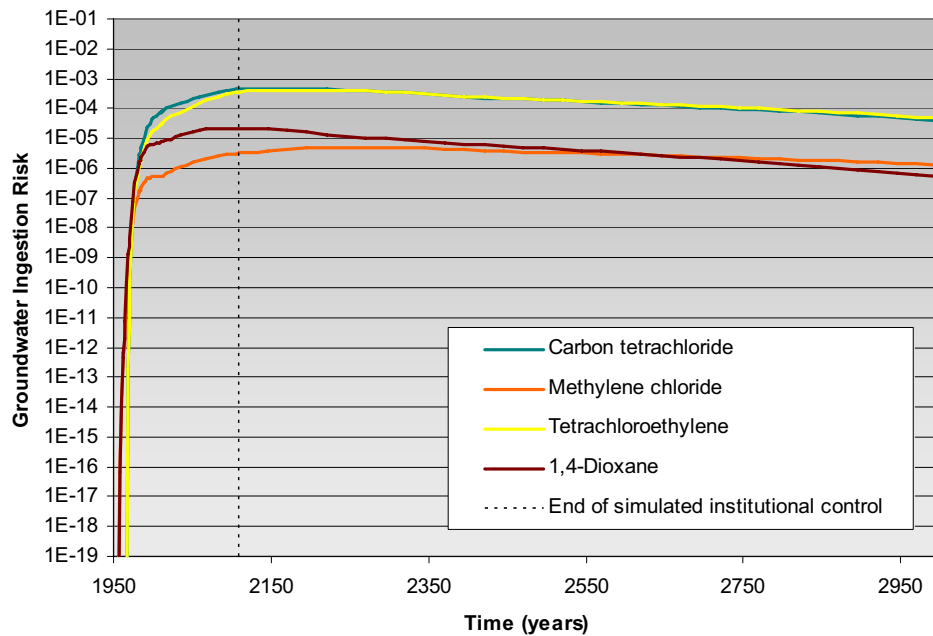
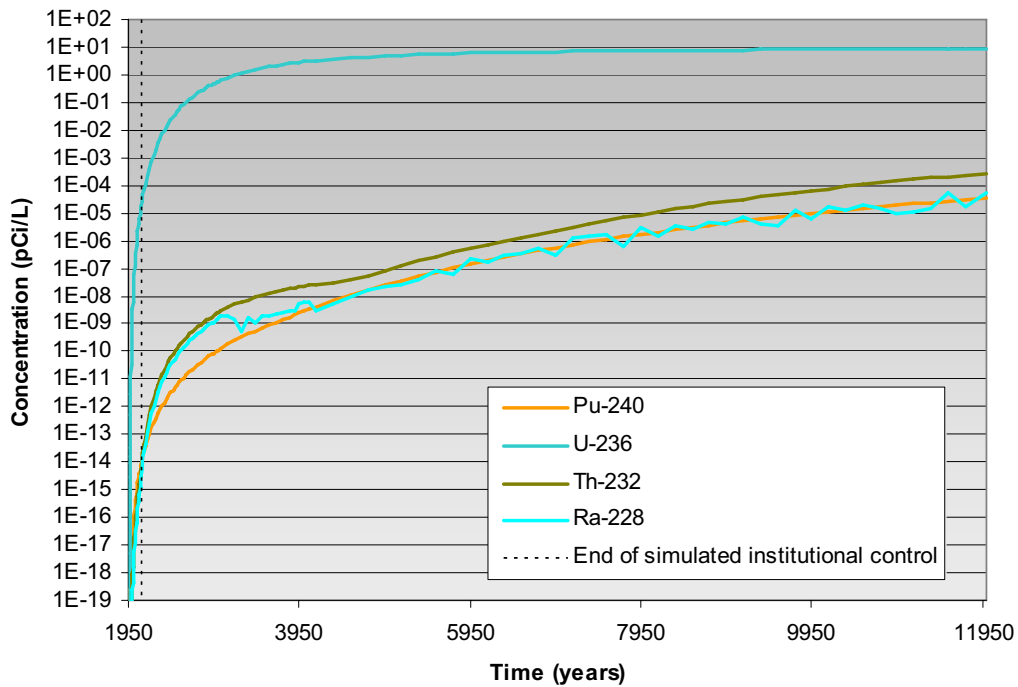Figure 6-87. Simulated maximum groundwater concentrations at the Subsurface Disposal Area boundary for Group 11 contaminants over 1,000 years.
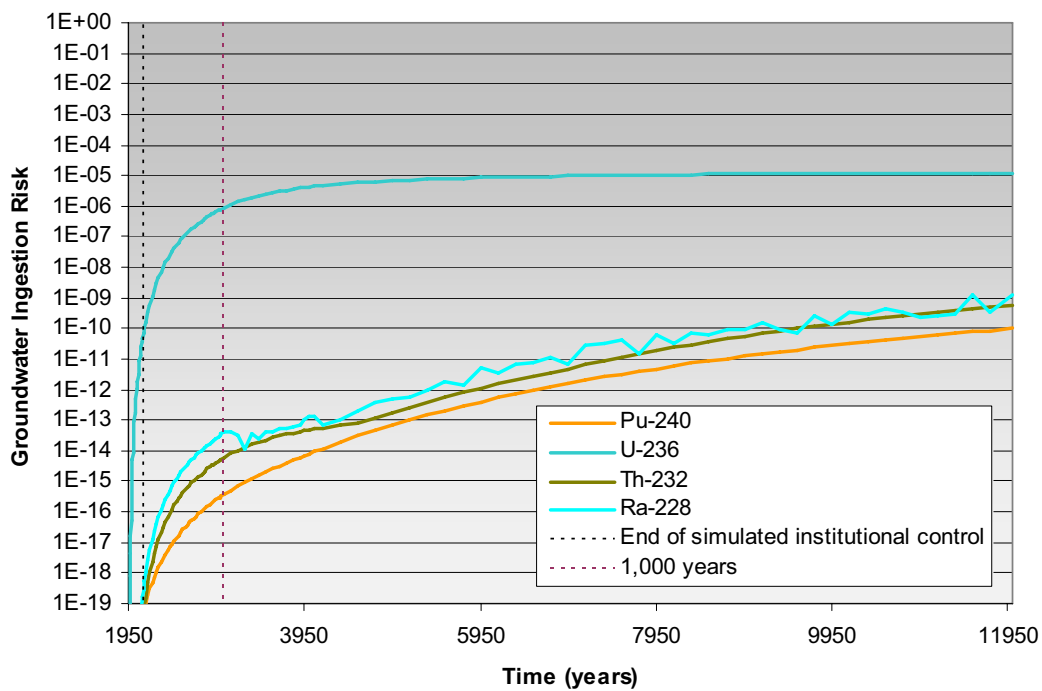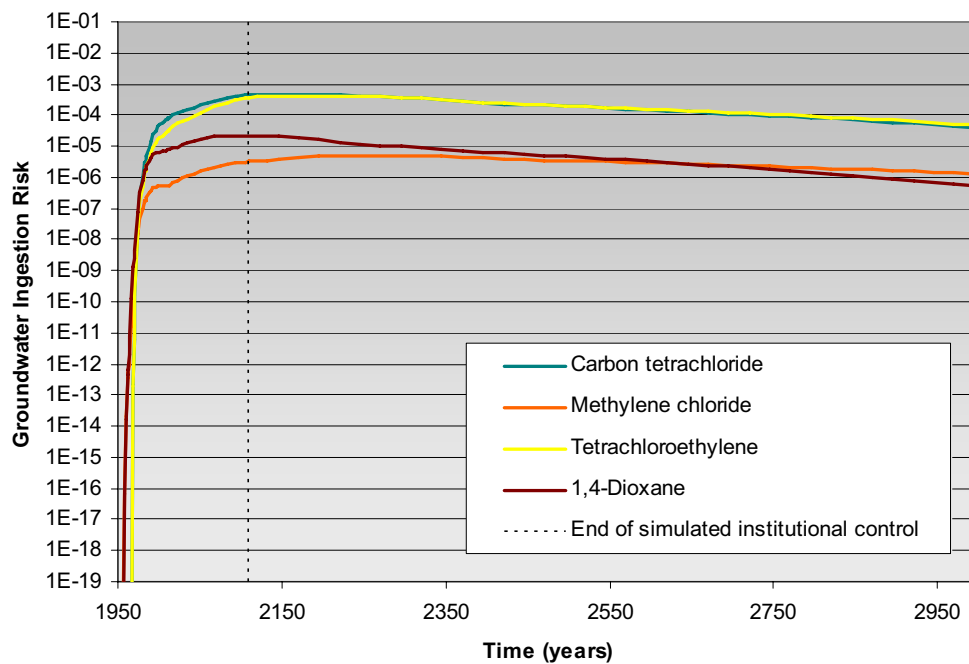

Figure 6-88. Groundwater ingestion risk at the Subsurface Disposal Area boundary for Group 11 contaminants over 1,000 years.
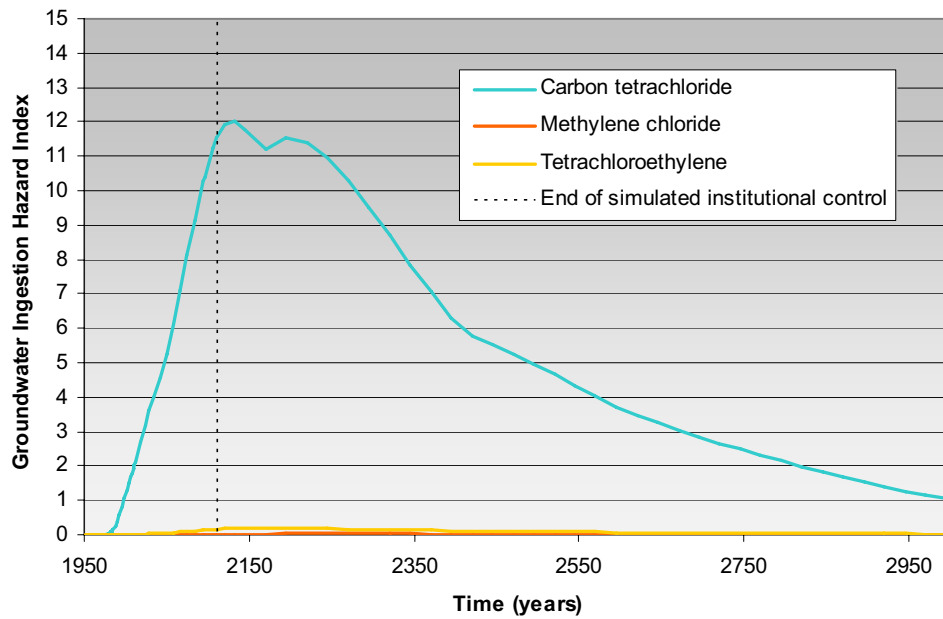
Figure 6-89. Groundwater ingestion hazard index at the Subsurface Disposal Area boundary for Group 11 contaminants over 1,000 years.
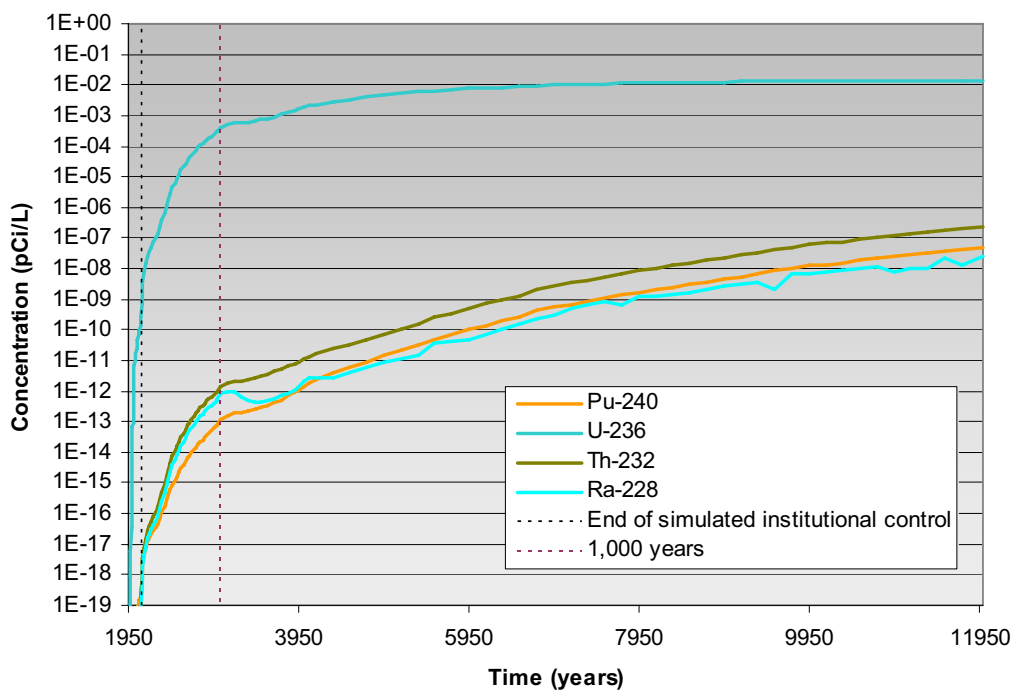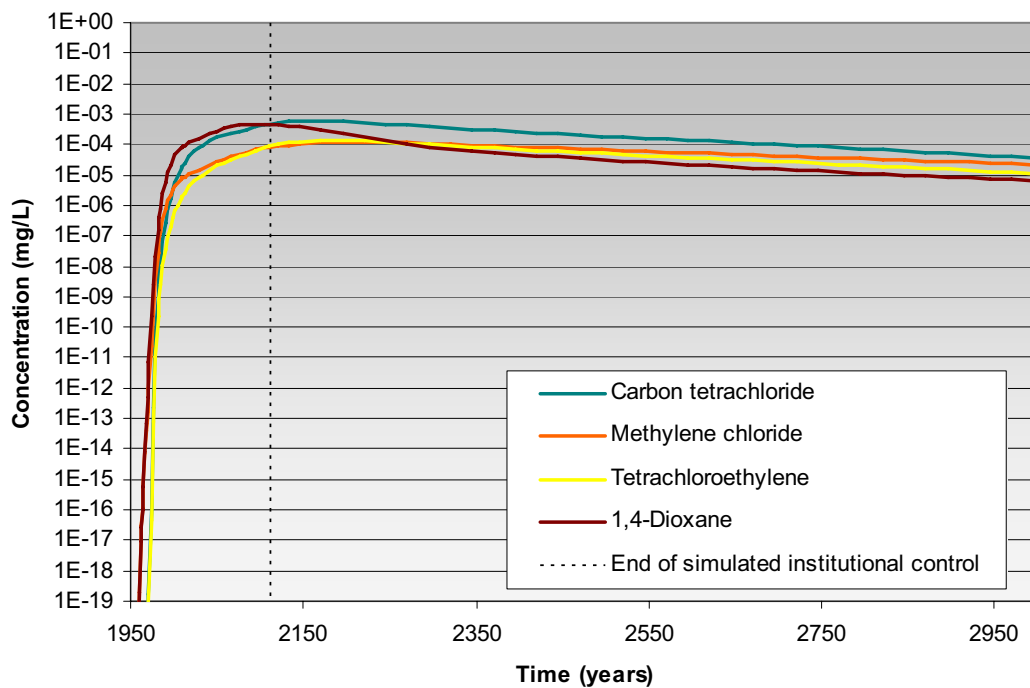

Figure 6-90. Simulated maximum groundwater concentrations for Group 11 contaminants at the southern boundary of the Idaho National Laboratory Site over 1,000 years.
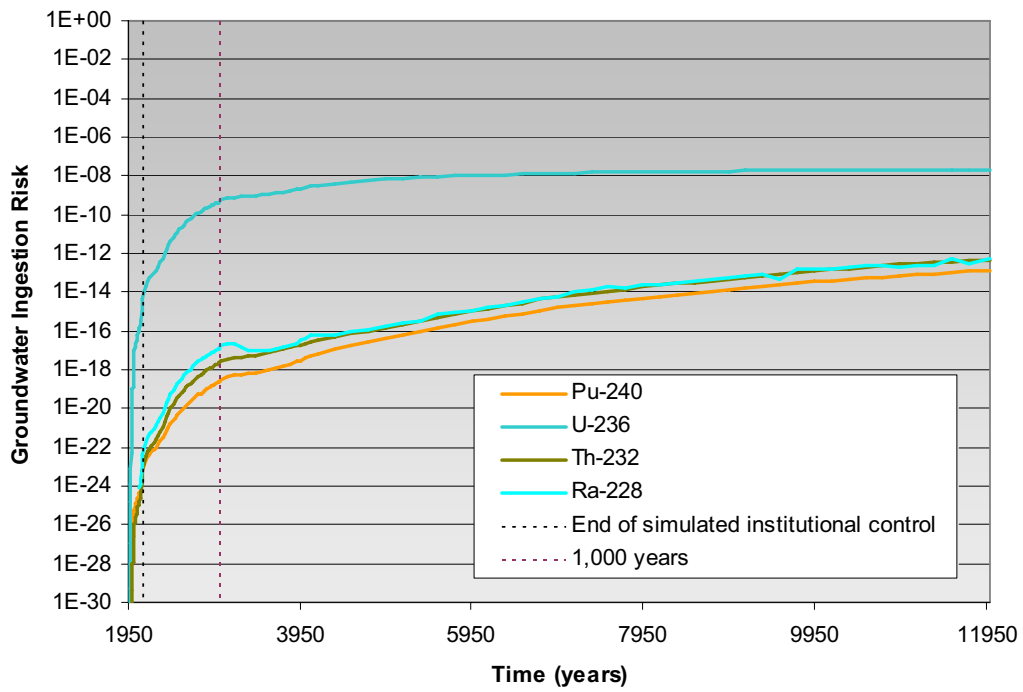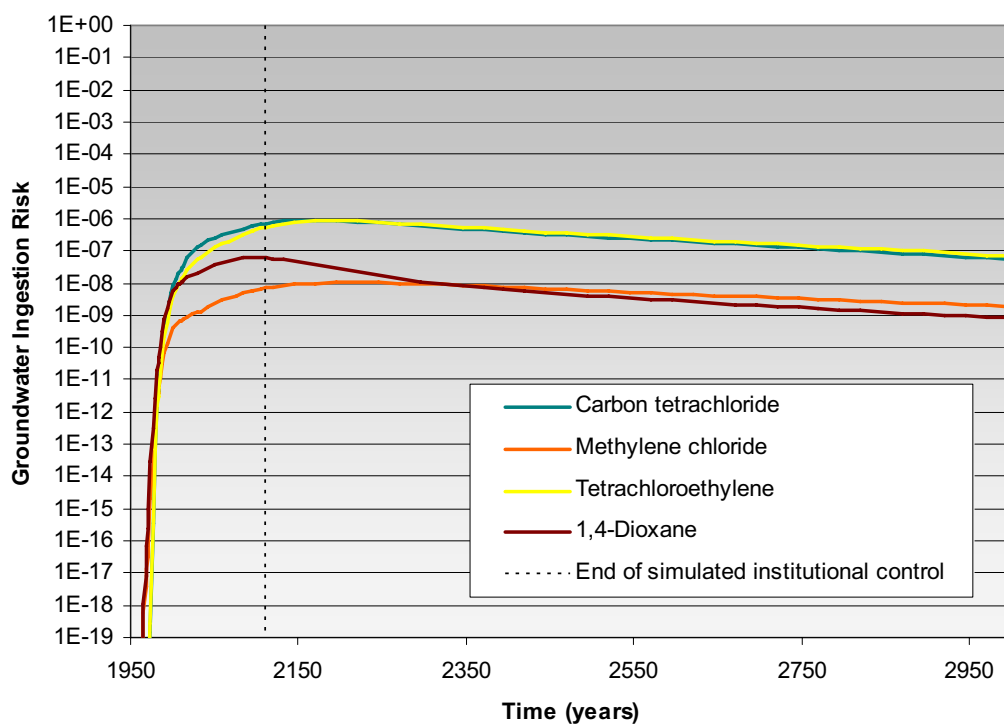
Figure 6-91. Simulated maximum groundwater ingestion risk for Group 11 contaminants at the southern boundary of the Idaho National Laboratory Site over 1,000 years.
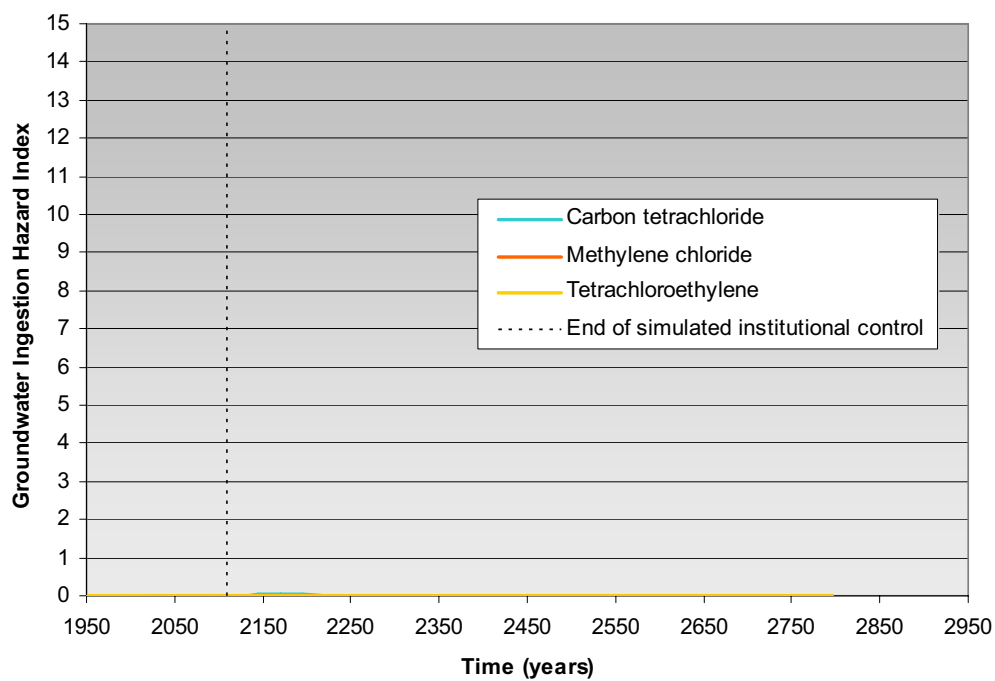
Figure 6-92. Simulated maximum groundwater ingestion hazard index for Group 11 contaminants at the southern boundary of the Idaho National Laboratory Site over 1,000 years.
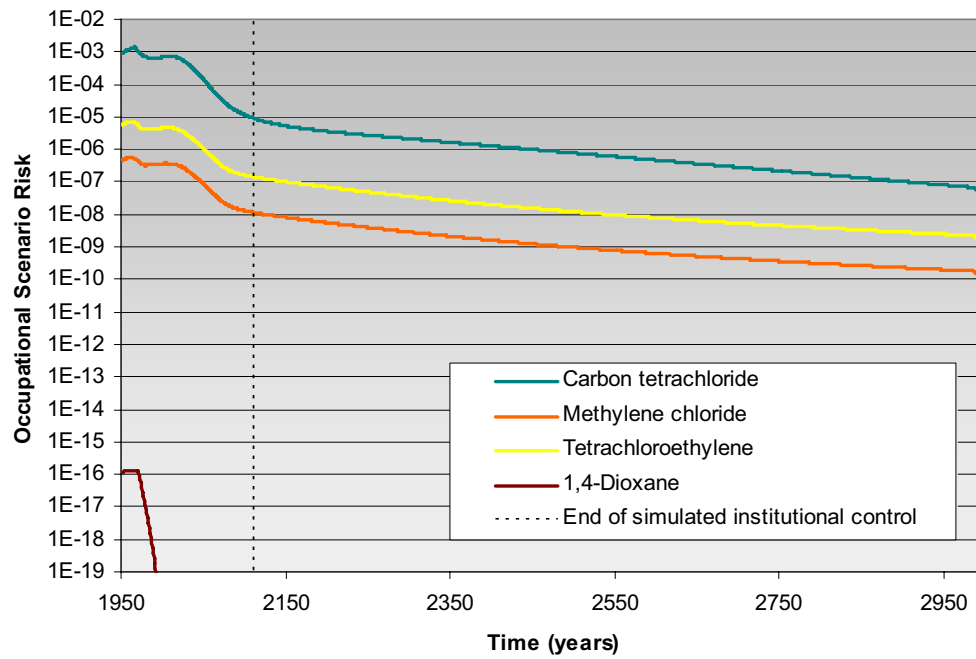
Figure 6-93. Simulated occupational scenario risk for Group 11 contaminants.
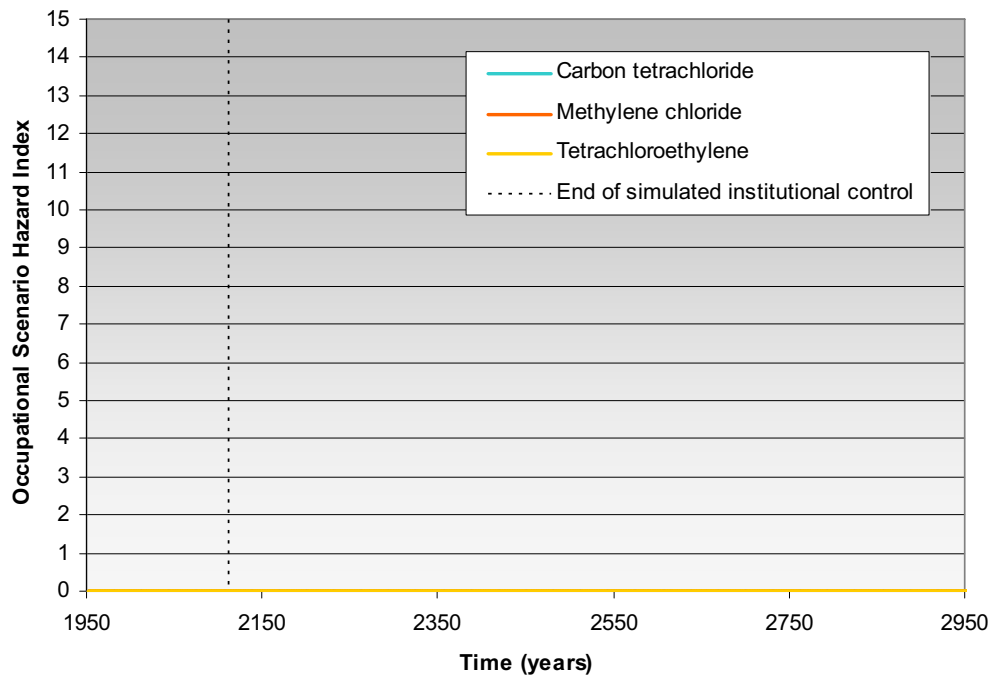
Figure 6-94. Simulated occupational scenario hazard index for Group 11 contaminants.

6.5   Uncertainties in the Human Health Baseline Risk Assessment

This section presents uncertainties associated with RI/BRA risk estimates. Uncertainties are classified in three broad categories: (1) scenario uncertainty, (2) model uncertainty, and (3) parameter uncertainty. Each category is discussed in the following subsections.

6.5.1   Scenario Uncertainty

Scenario uncertainty incorporates uncertainty associated with future land use at the INL Site and the choice of exposure scenarios assessed. Scenario choices, which were developed through consensus by DOE, DEQ, and EPA (Holdren and Broomfield 2004), were described earlier as critical assumptions for overall risk assessment. Furthermore, many assumptions are based on scenario choices, making scenario uncertainty difficult to quantify. Chosen scenarios are consistent with INL Site land-use projections (DOE-ID 1995), provide direct comparison with similar scenarios in other INL Site risk assessments, and generate reasonable and protective estimates of potential risk to human health.

An occupational exposure scenario was identified for the next 100 years because INL Site land use is expected to remain industrial for a minimum of 100 years (DOE 1995; Litus and Shea 2005). Furthermore, DOE Order 435.1 requires 100 years of institutional control after closure of a low-level waste (LLW) disposal facility (e.g., active LLW Pit in the SDA). Exposure parameters for a standard occupational scenario of 25 years of exposure for 40 hours a week may not be representative of a closed LLW disposal facility, but should provide protective estimates of potential occupational exposure. The choice of exposure parameter values is discussed in more detail in Section 6.5.3.

After the assumed 100-year institutional control period, land use at RWMC is assumed to remain restricted (Holdren and Broomfield 2004); however, parts of the INL Site could be returned to public use. Though future residential development at the INL Site may seem improbable, the RI/BRA assumption of residential use near the SDA generates protective risk estimates. Other scenarios (e.g., recreational use) would produce lower potential risk estimates. Direct intrusion into the waste would be unlikely because of deed restrictions and other closure procedures at RWMC. Therefore, the residential scenario addressed people living next to the SDA, but did not assess intrusion directly into the waste. Intrusion is addressed separately in Section 6.6.

6.5.2   Model Uncertainty

Model uncertainty describes the degree to which a model represents the physical system that it simulates. All models are simplifications of a real physical system. Issues are (1) whether models contain enough detail to adequately represent the physical system and (2) whether appropriate inputs can be chosen to emulate that physical system. As with scenario uncertainty, quantifying model uncertainty is nearly impossible. At best, uncertainty can be minimized by comparing results to known solutions and by calibrating the model to measured data.

Models used for this risk assessment were compared to measured data. Some model components had fewer available comparison data than others. For example, practically no data exist to calibrate the source-release and biotic-transport models, a limited data set is available for calibrating the dissolved-phase transport model, and a substantial data set is available for calibrating VOC transport. Section 5.2 presents results of comparisons for the transport model. The following list identifies those characteristics that have the greatest effect on model uncertainty:

- Contaminant inventory and release mechanisms are primary sources of uncertainty in model results. Uncertainties in the flow and transport models potentially affect groundwater pathway concentrations but not usually to the extent of source-release modeling uncertainties.

- The amount of water infiltrating through the waste, contacting waste, and leaching contaminants from the waste greatly impacts groundwater pathway concentrations. Current estimated infiltration rates ranging from background to as high as 10 cm/year (4 in./year) are reasonably conservative for the RI/BRA model. These infiltration rates, applied as constants in perpetuity, should be conservative because, over time, natural processes of revegetation are likely to reduce overall infiltration toward lower background rates.

- Uncertainty in the rate and direction of water and contaminant movement undergoing preferential flow through the fractured basalt portions of the vadose zone is addressed through a hydrologic parameterization that ensures rapid movement without any chemical interaction that would slow transport.

- The low-permeability region included in the aquifer flow and transport simulation has a large impact on predicted groundwater pathway concentrations. This low-permeability region limits dilution that may be occurring. Simulated aquifer concentrations in this region are dominated by water and contaminant influx from the vadose zone because of low velocities in the aquifer while water diverts around the low-permeability zone.

- Use of mostly steady-state flow conditions in the vadose zone also increases uncertainty. This, coupled with an assumption of linear equilibrium sorption, limits any potential influence from reactive transport that may be rate limited. While this assumption is likely appropriate at depths in the vadose zone where transient events get dampened, it may not be as appropriate in the near-field source area.

A combination of site-specific data, information from published literature, and professional judgment was used to parameterize models for this RI/BRA. Personnel from DOE, DEQ, and EPA collaborated to develop an acceptable modeling approach to predict release and transport. The goal is to be reasonably conservative in modeling—not excessively conservative (i.e., substantially overpredicting concentrations) or nonconservative (i.e., substantially underpredicting concentrations). In general, conservative values (i.e., values that maximize simulated media concentrations and risk) were applied when site-specific data were not available. Therefore, predicted concentrations and their related risk estimates will support risk management decisions that are protective. Section 6.5.3.2 presents quantified sensitivity analyses that address those parameters identified by DOE, DEQ, and EPA.

Of particular note, in the context of model uncertainty, is simulating media concentrations far into the future (i.e., 100, 1,000, and 10,000 years). Model calibration is limited because contamination is not widespread in the SDA environment (except for VOCs), and well-defined plumes and trends useful for model calibration do not exist. Uncertainty associated with absence of calibration data is addressed by DOE, DEQ, and EPA in the selection of reasonably conservative assumptions and parameters and by

assessing sensitivity associated with the results. Parametric sensitivity cases presented in Section 6.5.3 were identified for analysis based on this approach.

6.5.3   Parameter Uncertainty

Many parameters used as inputs to the models have associated uncertainties. Conservative assumptions for parameters were developed to provide reasonable risk estimates; however, as conservative assumptions were made at each step in the process, the resulting degree of cumulative conservatism was difficult to determine. Evaluations of uncertainty can range from a qualitative assessment to sophisticated methods that propagate uncertainty through models used to derive original risk estimates. Many simulations were performed to determine the probable range of uncertainty for specific parameters. Uncertainty is addressed qualitatively in Section 6.5.3.1. Quantified parametric sensitivity analysis is discussed in Section 6.5.3.2.

6.5.3.1   Qualitative Uncertainty Analysis. This section qualitatively assesses overall uncertainty. Contaminants were identified in the original contaminant screening documented in the Work Plan (Becker et al. 1996). The number of contaminants evaluated in this analysis was gradually reduced through iteratively refined risk assessments (Loehr et al. 1994; Burns et al. 1995; Becker et al. 1998; Holdren et al. 2002) (see Section 3.4.1). As in earlier assessments, risk estimates developed for this RI/BRA are products of a four-step process:

1.   Collect and evaluate data

2.   Assess exposure

3.   Assess toxicity

4.   Characterize risk.

Uncertainties in each of these steps are discussed in the following subsections.

6.5.3.1.1   Data Collection and Evaluation—The nine-step process recommended by EPA (1989) to assess data usability for risk assessment is listed below:

1.   Gather all available data and sort by medium

2.   Evaluate the analytical methods used

3.   Evaluate data in accordance with sample quantitation limits

4.   Evaluate data in accordance with data flags and qualifiers

5.   Evaluate data in accordance with contamination found in laboratory blanks

6.   Evaluate tentatively identified compounds

7.   Compare data to background concentrations

8.   Develop the data set for risk assessment

9.   If appropriate, screen the list to limit the number of contaminants to be evaluated.

Samples are handled by analytical laboratories subcontracted to ICP and certified by the Contract Laboratory Program. Numerous quality assurance and quality control precautions are implemented during sampling, handling, analysis, and data management to ensure that sampling data meet data usability criteria (see Section 4.1.6) and are assigned the appropriate data quality flags. Even with this level of rigor in sampling and analysis methods, data occasionally pass all the tests, but are still suspect. Because these data may support important decisions, further data review may be justified.

In addition to contaminant concentrations, other types of data were used in the models but were not subjected to standard quality control procedures associated with determining media concentrations using the Contract Laboratory Program. All available data were evaluated to determine whether they were of sufficient quality to be used as input for modeling. Model inputs are discussed in Section 5. Site-specific data were used when available and of sufficient quality. When site-specific data were not available, literature was reviewed to determine values appropriate for conditions in the SDA. Examples of other types of data used include the following:

- **Lithologic logs**—Lithologic logs from well-drilling operations were used to determine relative thickness of basalt flows and interbeds in the subsurface model.

- **Soil-to-water partition coefficients**—Priority was given to site-specific data, as recommended by EPA (EPA 1999). When site-specific data were not available, national databases were searched for appropriate values. Values were reviewed for appropriateness (Riley and Lo Presti 2004). (Note that flow through basalt is assumed to occur in fractures. Partitioning is minimal and assumed to be zero in the model.)

- **Container-failure data**—Waste-retrieval operations provided container-failure data.

- **Corrosion rates of beryllium reflector blocks**—Rates were estimated analytically based on sample data corrected for site-specific conditions.

- **National Bureau of Standards data**—Corrosion-rate estimates for stainless steel were derived from data from the National Bureau of Standards.

- **Contaminant inventory**—The contaminant inventory was compiled through review of disposal records and direct contact with waste generator personnel to validate the amounts (see Section 3.3).

Comparing modeling results to measured concentrations is the ultimate test of a model and all its associated input. Comparisons of simulated concentrations to measured concentrations from the aquifer and vadose zone are discussed in Section 5.2.5. In most cases, the model provided a reasonable match with measured data. In a few cases, model predictions were grossly inconsistent with measured concentrations. Technetium-99 and I-129 are the primary contaminants where modeled results do not match measured data. Further work is recommended (see Section 7) for the feasibility study so that remedial actions can be evaluated more accurately. A sensitivity analysis (see Section 6.5.3.2) addresses those parameters identified in the Second Addendum to the Work Plan (Holdren and Broomfield 2004) as most important for understanding the uncertainty in base-case risk.

6.5.3.1.2   Exposure Assessment—Uncertainties associated with the exposure assessment are produced by estimating source-term inventories; characterizing transport, dispersion, and transformation of contaminants of potential concern in the environment; establishing exposure settings; and deriving estimates of chronic intake. Initial characterization that defines the exposure setting for a site requires many professional judgments and assumptions. Areas where a quantitative estimate of uncertainty cannot be achieved, because of the inherent reliance on professional judgment, include

definition of the physical setting, characteristics of the population, and selection of chemicals included in the risk assessment.

Contaminant inventories used in the analysis introduce uncertainty into model results. As discussed in Section 3.3, several corrections, revisions, and updates were applied to original source-term inventories (INEL 1995a, 1995b). Corrections and refinements were adopted for the risk assessment. Additional minor changes may develop as Waste Information and Location Database verification proceeds. The inventory used for this assessment was frozen as of October 2004. Minor corrections to the inventory since that time, based on Waste Information and Location Database verification, were not included in the risk assessment.

Release parameters used in the source-term model also can introduce large uncertainty in the exposure assessment. For example, the corrosion rate of fuel is unknown, but a conservative estimate is used to predict release of fission products from fuel test specimens in buried waste.

Uncertainties from subsurface fate and transport modeling also contribute to uncertainties in the exposure assessment. Primary uncertainties are contaminant inventories and release rates. Also important are amount and timing of infiltration through buried waste, the possibility of preferential pathways through the vadose zone, and a low-permeability region in the aquifer that affects dilution of contaminants emanating from the vadose zone. Sensitivity analyses related to these uncertainties have been performed in previous assessments; however, not all results are reproduced here.

Exposure and intake parameters applied in this RI/BRA are EPA default values, developed to provide a reasonable upper-bound estimate of exposure. The combination of exposure parameters protects the population at greater than 90% for each exposure pathway. In addition, an exposure assumption is that a worker or resident is at the site to receive the exposure. As noted in Section 6.5.1, the assumption is conservative.

6.5.3.1.3 *Toxicity Assessment*—Several important measures of toxicity are needed to assess risk to human health. For example, EPA-specified reference doses are applied to oral and inhalation exposure to evaluate noncarcinogenic and developmental effects, and EPA-specified slope factors are applied to oral and inhalation exposure to evaluate carcinogens. Reference doses are derived by applying uncertainty factors and other modifiers to concentrations at no-observable-effect level or lowest-observable-adverse-effect level. Uncertainty factors are used to account for variation in sensitivity of human subpopulations and uncertainty inherent in extrapolating results of animal studies to humans. Modifying factors account for additional uncertainties in the studies used to derive the no-observable-effect level or lowest-observable-adverse-effect level. Uncertainty associated with slope factors is accounted for by applying an assigned weight-of-evidence rating that reflects the likelihood that a toxicant is a human carcinogen. Weight-of-evidence classifications are tabulated in Table 6-3, and factors used to derive reference doses are discussed in Section 6.3.

6.5.3.1.4 *Risk Characterization*—The last step is risk characterization, which is the process of integrating results of exposure and toxicity assessments. Uncertainties defined throughout the analysis process are combined and presented as part of risk characterization to provide an understanding of overall uncertainty inherent in risk estimates. This qualitative assessment of uncertainty is shown in Table 6-10. In general, risk results are biased high (i.e., conservative) to be protective of human health.

Table 6-10. Human health uncertainty factors.

Uncertainty Factor	Effect of Uncertainty on Estimating Risk	Comment
Source-term assumptions	May overestimate	Release parameters are based on site-specific data, where available, but lack of information about geochemistry, condition of containers, and information within the waste precludes full understanding of release rates. Conservative assumptions were used when data were uncertain, most likely leading to overprediction of Tc-99 concentrations compared to measured concentrations.
Source-term inventory	May overestimate	The model used best-estimate inventory estimates based on a more complete accounting of all isotopes compared to those used in previous assessments (see Section 3.3). Upper-bound-inventory sensitivity cases show that uncertainty in total risk from inventory uncertainty is less than a factor of 2.
Infiltration rate	May overestimate	Base-case simulations apply spatially variable infiltration rates based on site-specific measurements in disturbed soil to simulate the waste zone. The value is likely high, on average, through the waste; this would increase contaminant flux into the vadose zone and subsequent transport to the aquifer. Sections 6.5.3.2.2 though 6.5.3.2.4 discuss the effect of changing the infiltration rate on the risk results.
Moisture content	May overestimate or underestimate	Soil-moisture content varies seasonally in the upper vadose zone and may be subject to measurement error. The amount of moisture is important for solubility-limited contaminants (e.g., uranium). The mass released and available for transport depends on the amount of moisture in the waste zone.
Water table fluctuation	May overestimate	Flow reversals, which are not evaluated in the RI/BRA, would cause additional spreading (i.e., dilution) and reduce groundwater concentrations.
Spreading area influence	May overestimate	RI/BRA simulations do not include the effect of water migrating from spreading areas along interbeds (at depth) to regions beneath the SDA, though some influence has been observed (Nimmo et al. 2002). In general, additional water from spreading areas would dilute contaminant concentrations in the vadose zone, decreasing risk relative to predicted values, as was demonstrated in ABRA modeling (see Section 5 of Holdren et al. 2002).

Table 6-10. (continued).

Uncertainty Factor	Effect of Uncertainty on Estimating Risk	Comment
Interbed gaps	May underestimate	Base-case simulations include B-C and C-D interbeds that are modeled as continuous but very thin in places. Interbed gaps are known to exist, particularly in the B-C interbed. If gaps occurred at key places (e.g., in a region with large fractures and high infiltration), risk would be underestimated. The sensitivity case in Section 6.5.3.2.5 simulates the complete absence of the B-C interbed and shows total risk would increase roughly by a factor of 2. Gaps in the interbeds would have much less effect than complete absence of an interbed. Furthermore, deeper interbeds, though known to exist, are not simulated because data are not sufficient to parameterize them. Omitting these deeper interbeds produces higher risk estimates.
Low-permeability zone in the aquifer	May overestimate	An extensive low-permeability zone is implemented in the model in keeping with interpreted data from pump tests (see Section 5.2.4.5). Without this zone, dilution would be much greater, as shown in Section 6.5.3.2.7. The risk would be reduced nearly an order of magnitude if the low-permeability zone were not there.
Surface soil concentrations	May underestimate	Biotic modeling is based on a homogenized source term to produce average surface soil concentrations. This is representative of concentrations to which a residential receptor living next to the SDA would be exposed.
Chemical form assumptions	May overestimate or underestimate	In general, methods and inputs used in contaminant migration calculations, including assumptions made about the chemical forms of contaminants, were chosen to err on the protective side.
Exposure scenario assumptions	May overestimate	The likelihood of future land-use scenarios has been qualitatively evaluated as improbable for residential and credible for industrial scenarios. If future residential use very near the SDA does not occur, then future residential risk estimates are overestimated. Both surface exposure pathway and groundwater pathway risk estimates for the future residential scenario diminish sharply with distance from the SDA (see groundwater risk isopleths in Section 6.4.2.4).
Exposure parameter assumptions	May overestimate	Assumptions about media intake, population characteristics, and exposure patterns are EPA default values. Exposure parameters are defined by EPA to describe reasonable maximum exposure to an individual.

Table 6-10. (continued).

Uncertainty Factor	Effect of Uncertainty on Estimating Risk	Comment
Groundwater well location	May overestimate	Groundwater ingestion risks are calculated using maximum concentrations outside the SDA in the low-flow region in the aquifer. Other well locations would show lower risk. In addition, the low-flow zone beneath the SDA would not support a family or irrigation well; therefore, no exposure would occur to the high concentrations simulated. (Also, see "low-permeability zone in the aquifer" in this table.)
Exposure duration	May overestimate	Assuming that an individual will work or reside at the SDA for 25 or 30 years is conservative. Short-term exposures involve comparison to subchronic toxicity values, which are generally less restrictive than chronic values.
Not considering biotic decay and other chemical degradation mechanisms	May overestimate	Biotic decay and other chemical degradation would tend to reduce contamination over time. Though some decay products could be produced that are as toxic as the parent product, decay, in general, would tend to reduce risk.
Use of residential intake value for inhalation for occupational scenarios	May slightly overestimate	Standard exposure factors for inhalation have the same conservative value for occupational as for residential scenarios, though occupational workers would not be on the Idaho National Laboratory Site all day.
Use of cancer slope factors	May overestimate	Slope factors for chemicals are associated with upper-95th-percentile confidence limits. Their use is likely to result in overestimating actual risk. For radionuclides, slope factors are maximum-likelihood estimates and represent a best estimate for the dose response, assuming a linear effect at low exposure levels.
Toxicity values (i.e., slope factors and reference doses) derived primarily from animal studies	May overestimate	Extrapolation from animals to humans may induce error caused by differences in absorption, pharmacokinetics, target organs, enzymes, and population variability. Because factors are included to account for uncertainty, toxicity values are most likely conservative.
Toxicity values (i.e., slope factors and reference doses) derived primarily from high doses	May overestimate	Toxicity values (i.e., slope factors and reference doses) are derived primarily from high doses, while most exposures are at low doses. Linearity is assumed at low doses, with no threshold concentration for adverse effects. Exposure assumptions tend to be conservative.

Table 6-10. (continued).

Uncertainty Factor	Effect of Uncertainty on Estimating Risk	Comment
Toxicity values (i.e., slope factors and reference doses) and classification of carcinogens	May overestimate	Not all toxicity values represent the same degree of certainty, and all are subject to change as new evidence becomes available. Because factors are included to account for uncertainty, toxicity values are most likely conservative.
Lack of toxicity values (i.e., slope factors and reference doses)	May underestimate	Revised screening in Section 3.4 shows that contaminants in the SDA that do not have EPA toxicity values will have negligible impact on overall risk at the site. For two contaminants not previously assessed, alternative toxicity values (OEHHA 2003) were used to assess health risk. Other contaminants have such small inventories that neglecting them in the risk assessment has minimal impact to the total risk estimate.
Risks and hazard quotients summed across pathways	May overestimate or underestimate	Synergistic or antagonistic effects of mixtures of contaminants are not quantified.
Modeling over long simulation periods	May overestimate	Adopting parameters that are biased high, as is done in this RI/BRA to ensure protectiveness, can substantially compound conservatism over long simulation periods.

ABRA = Ancillary Basis for Risk Analysis (Holdren et al. 2002)
EPA = U.S. Environmental Protection Agency
RI/BRA = remedial investigation and baseline risk assessment
SDA = Subsurface Disposal Area

This uncertainty factor also is addressed in the parametric sensitivity analysis in Section 6.5.3.2.

6.5.3.2 *Parametric Sensitivity Analysis.* The sensitivity of several parameters was analyzed to assess the effect of uncertainty on overall risk results. Parametric sensitivity cases were identified by DOE, DEQ, and EPA, as specified in the Second Addendum (Holdren and Broomfield 2004) or determined in subsequent discussions. Table 6-11 lists sensitivity cases that are assessed. With the exception of inventory sensitivity, analysis in this RI/BRA focuses on the groundwater ingestion pathway. Additional parameters were evaluated in previous analyses. Results of those studies were incorporated into this modeling effort. Section 5 provides additional details.

Table 6-11. Parametric sensitivity cases.

Parameter or Characteristic	Base Case	Sensitivity Case
Inventory amounts	Best-estimate inventory	Upper-bound inventory for all contaminants
Background infiltration rate	Conservative value of 1 cm/year from U.S. Geological Survey test plot	Reduced background infiltration rate of 0.1 cm/year
Low infiltration inside the SDA	Spatially variable infiltration with a net average of 5 cm/year	Low uniform infiltration rate of 0.1 cm/year
High infiltration inside the SDA	Spatially variable infiltration with a net average of 5 cm/year	High uniform infiltration rate of 23 cm/year
Gaps in the B-C interbed	Continuous interbeds, very thin in places; based on kriged lithology	B-C interbed completely omitted
Effect of Pit 4 retrieval and beryllium-block grouting	Retrieval of targeted waste from a defined area in Pit 4 and grouting of most beryllium blocks	No retrieval from Pit 4 or grouting of beryllium blocks
Low-permeability zone beneath the SDA	Permeability of 153 mD	Permeability of 712,000 mD
Sorption in vadose zone interbeds	Colloids are filtered by interbeds, which are modeled by applying a K_d of 2,500 mL/g for Pu-239 and Pu-240	No sorption in any of the interbeds

SDA = Subsurface Disposal Area

In general, parametric sensitivity analysis involves varying one parameter or characteristic while holding all other factors constant, then assessing the overall effect on the risk assessment of changing the one parameter. Typically, extreme values are chosen for the parameter being evaluated. For example, to assess the possible impact of high infiltration compared to the base case, an infiltration value of 23 cm/year is used, which is equivalent to the entire average annual precipitation. Each of the factors identified in Table 6-11 are discussed in the following subsections.

6.5.3.2.1 *Inventory Uncertainty*—Upper-bound inventories were used to address inventory uncertainty. Section 3.3 summarizes work that refined inventory estimates used for this analysis. Table 6-12 shows the comparison of the best-estimate and upper-bound inventories used in simulations. Figure 6-95 shows total estimated risk for all pathways based on upper-bound inventory. The peak total risk increased from 7E-03 to 1E-02. The groundwater ingestion risk before the year 2110 is less than the scale shown on the figure. Figure 6-96 shows the upper-bound inventory hazard index for all pathways. The peak hazard index increased from 15 to 21. Table 6-13 shows base-case and upper-bound risk estimates and hazard indexes by contaminant.

Table 6-12. Best-estimate and upper-bound inventories used in the baseline risk assessment and sensitivity analysis.

Simulation Group	Contaminant	Best-Estimate Inventory[a]	Upper-Bound Inventory[a]
Group 1	Am-241	2.43E+05	3.24E+05
	Np-237	1.41E-01	2.88E-01
	U-233	2.12E+00	2.66E+00
	Th-229	7.14E-06	7.33E-06
Group 2	Am-243	1.18E-01	1.65E-01
	Pu-239 (colloidal)	2.33E+03	4.10E+03
	Pu-239	6.18E+04	8.47E+04
	U-235	4.88E+00	7.06E+00
	Pa-231	8.61E-04	5.19E-03
	Ac-227	4.29E-06	1.11E-05
Group 3	Pu-240 (colloidal)	5.22E+02	9.19E+02
	Pu-240	1.41E+04	2.18E+04
	U-236	1.45E+00	2.39E+00
	Th-232	3.51E+00	7.15E+00
	Ra-228	3.66E-05	6.99E-05
Group 4[b]	Pu-238	2.08E+03	2.84E+03
Group 5	U-238	1.48E+02	2.52E+02
	U-234	6.26E+01	9.52E+01
	Th-230	5.77E-02	7.49E-02
	Ra-226	6.51E+01	8.72E+01
	Pb-210	5.59E-07	5.99E-05
Group 6	Tc-99	4.29E+01	7.59E+01
	I-129	1.85E-01	3.21E-01
	Cl-36	1.64E+00	2.62E+00
Group 7	H-3	2.66E+06	Not simulated
Group 8	C-14	7.38E+02	1.09E+03
Group 9	Cs-137	1.68E+05	2.88E+05
	Nb-94	1.28E+02	2.14E+02
	Sr-90	1.32E+05	2.29E+05
	Th-228	2.66E-02	1.29E-01
Group 10	Nitrate	4.56E+08	6.35E+08
Group 11	Carbon tetrachloride	7.86E+08	9.61E+08
	1,4-Dioxane	1.95E+06	6.26E+06
	Methylene chloride	1.41E+07	1.55E+07
	Tetrachloroethylene	9.87E+07	2.70E+08
	Trichloroethylene[c]	9.72E+07	1.13E+08

a. Units are curies for radionuclides and grams for nonradionuclides.
b. Inventories for the remaining Group 4 contaminants are included with Group 5.
c. Risk for trichloroethylene was scaled for the base case. Complete simulation results will be presented in the feasibility study.
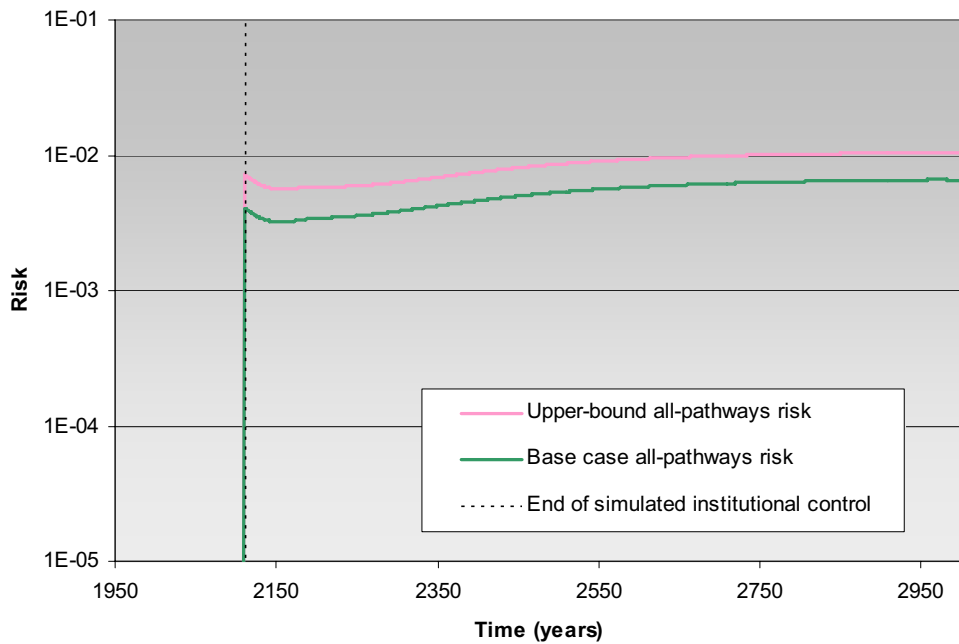
Figure 6-95. Comparison of estimated all-pathways risk at the Subsurface Disposal Area boundary for best-estimate and upper-bound inventories sensitivity case.
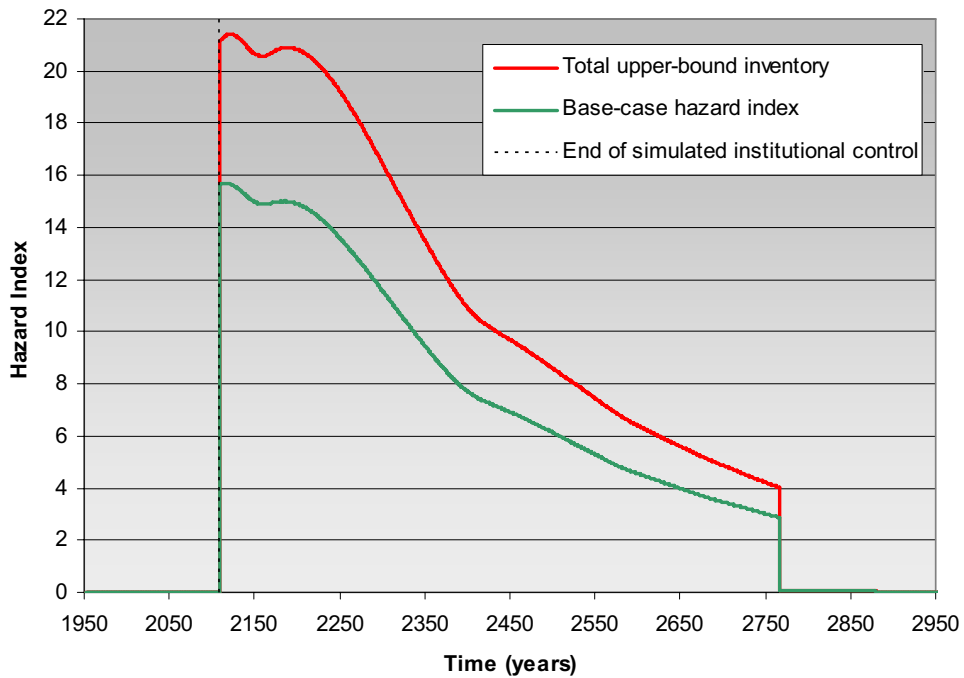
Figure 6-96. Comparison of estimated all-pathways hazard index at the Subsurface Disposal Area boundary for best-estimate and upper-bound inventories sensitivity case.

Table 6-13. Comparison of risk estimates and hazard indexes for the residential exposure pathway at the Subsurface Disposal Area boundary for the 1,000-year simulation period based on best-estimate and upper-bound inventories.

Contaminant	Best Estimate	Upper-Bound Inventory
Risk		
Ac-227	5E-07	9E-07
Am-241	3E-03	5E-03
Am-243	1E-07	1E-07
C-14	1E-05	2E-05
Cl-36	2E-06	3E-06
Cs-137	2E-03	3E-03
I-129	4E-05	7E-05
Nb-94	2E-06	3E-06
Np-237	7E-06	1E-05
Pa-231	3E-07	5E-07
Pb-210	3E-05	4E-05
Pu-238	1E-06	2E-06
Pu-239	3E-03	4E-03
Pu-240	6E-04	9E-04
Ra-226	7E-04	1E-03
Ra-228	3E-05	7E-05
Sr-90	1E-03	2E-03
Tc-99	3E-04	5E-04
Th-228	5E-05	1E-04
Th-229	4E-07	4E-07
Th-230	1E-08	2E-08
Th-232	3E-07	6E-07
U-233	4E-06	4E-06
U-234	6E-07	6E-07
U-235	2E-07	3E-07
U-236	9E-07	1E-06
U-238	1E-06	2E-06
Carbon tetrachloride	5E-04	6E-04
1,4-Dioxane	2E-05	7E-05
Methylene chloride	5E-06	6E-06
Tetrachloroethylene	7E-07	2E-06
Trichloroethylene[a]	9E-04	1E-03

Table 6-13. (continued).

Contaminant	Best Estimate	Upper-Bound Inventory
Hazard Index		
Carbon tetrachloride	1E+01	2E+01
Methylene chloride	3E-02	3E-02
Nitrate	1E+00	1E+00
Tetrachloroethylene	3E-01	1E+00

a. Trichloroethylene risk is scaled from carbon tetrachloride risk. Actual risk values will be computed in the feasibility study.

Risk estimate greater than 1E-05 or hazard index greater than or equal to 1.

The sensitivity case is intended to determine whether uncertainty in the inventory would modify the focus of the feasibility study. Two contaminants are notable: Np-237 and tetrachloroethylene. Risk for Np-237 within the 1,000-year simulation period is less than 1E-05 with the best-estimate inventory, and slightly greater than 1E-05 with the upper-bound inventory. However, Np-237 was identified as a contaminant with a groundwater ingestion risk greater than 1E-05 after 1,000 years. The hazard index for tetrachloroethylene is 3E-01 for the base case and 1E+00 for the upper-bound inventory. Tetrachloroethylene is largely collocated with carbon tetrachloride in organic sludge from the Rocky Flats Plant. These results indicate that substantial changes in inventory would not focus attention on different waste streams.

6.5.3.2.2   *Reduced Infiltration Outside the Subsurface Disposal Area*—This RI/BRA and previous assessments used a background infiltration rate of 1 cm/year for undisturbed sediment in areas outside the SDA. Continued monitoring has shown that the rate could be as low a 0.1 cm/year (see Section 5.2.6). Sensitivity cases were run to assess the potential effect of this substantially lower background infiltration rate. The concern was that using the higher, base-case rate might not be conservative when predicting aquifer concentrations because of a dilution effect from additional water. Figure 6-97 shows changes in total groundwater ingestion risk from radionuclides. Because Tc-99 and I-129 risks are overestimated (see Section 5.2.5), the plot shows the effect both with and without Tc-99 and I-129. The largest impact is in the initial peak from Tc-99 and I-129. The total peak increases from the base-case value of 3E-04 to 4E-04. When Tc-99 and I-129 are not included, the peak increases only about 1%. The net effect appears to be important for mobile contaminants (e.g., Tc-99, I-129, and nitrate) but less important for less mobile contaminants. To confirm this conclusion, impact on specific mobile contaminants is addressed. The Tc-99 risk increased from 2E-04 to 3E-04. Figure 6-98 shows the comparison of results for the base case and the lower infiltration case for both Tc-99 and I-129. Because of issues identified with Tc-99 simulations (see Section 5.2.5), nitrate results also are shown (see Figure 6-99). Additional infiltration outside the SDA dilutes contaminants and reduces impact to the aquifer, and the peak groundwater ingestion hazard quotient increases from 1 to nearly 2. Risks shown before the year 2110, during the simulated 100-year institutional control period, are shown only to compare the effect of variation in infiltration rates.
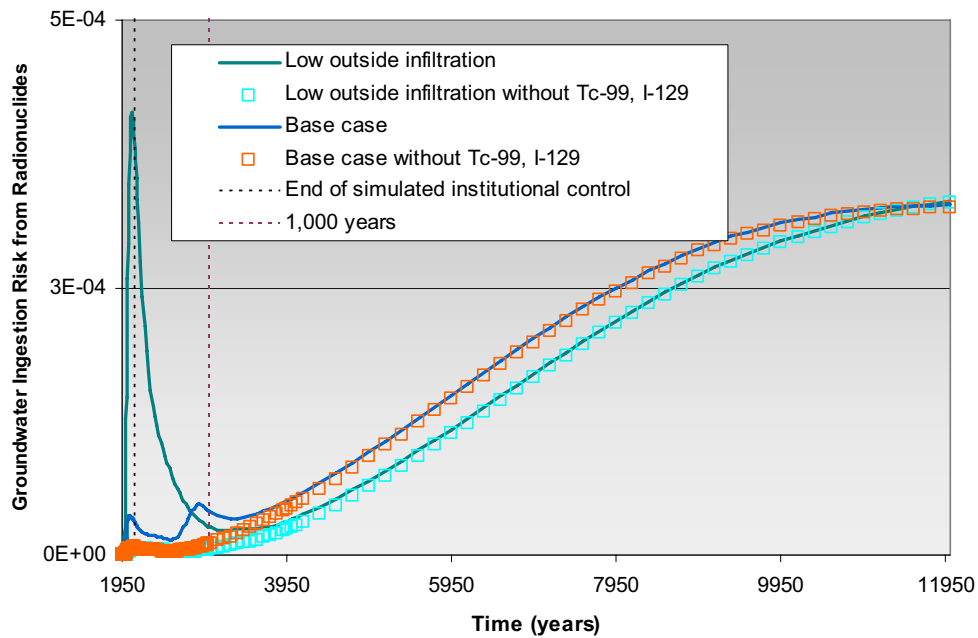
Figure 6-97. Groundwater ingestion risk from radionuclides comparing the base case to the reduced background infiltration sensitivity case.
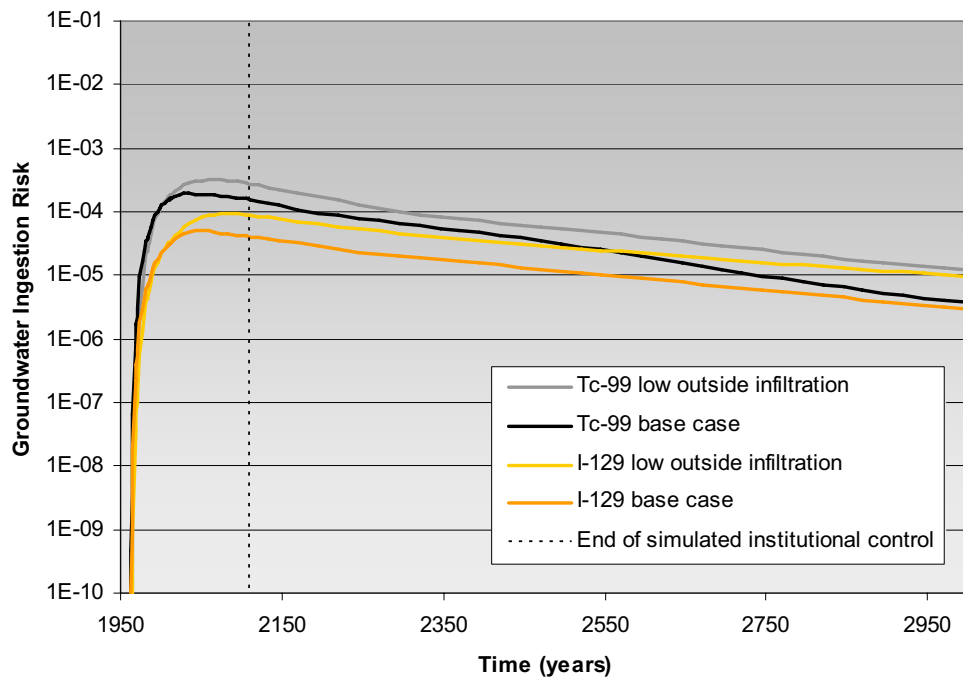
Figure 6-98. Comparison of estimated technetium-99 and iodine-129 groundwater ingestion risk for the reduced background infiltration sensitivity case.
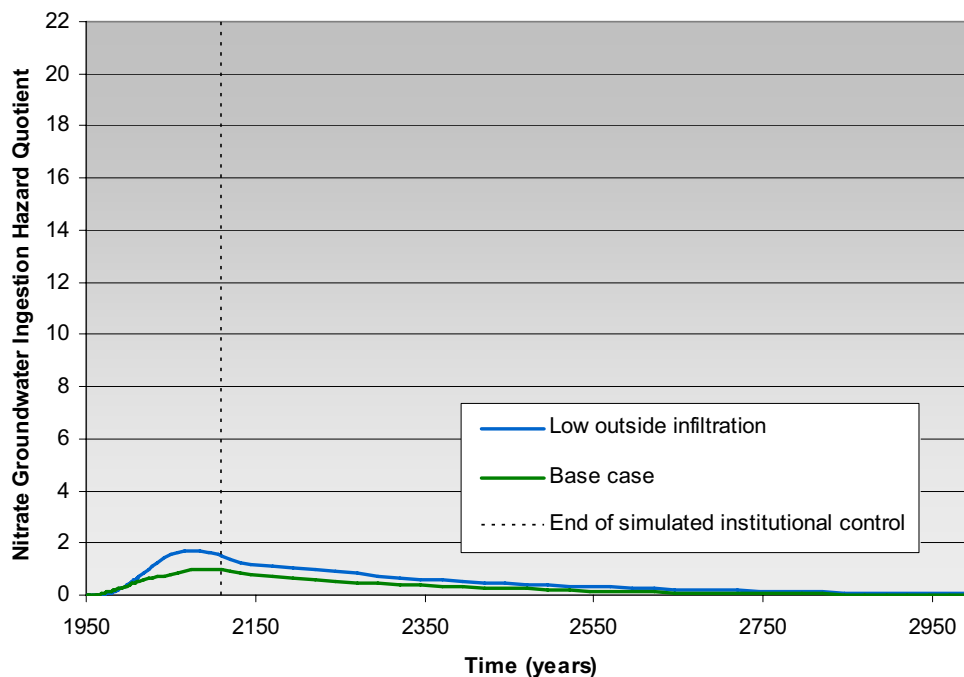
Figure 6-99. Comparison of estimated nitrate groundwater ingestion hazard quotient for the reduced background infiltration sensitivity case.

The conclusion evident from this analysis is that a substantially lower background infiltration rate (i.e., an order of magnitude reduction) would produce slightly higher risk estimates (e.g., a factor of 2 or less). Overall results of the RI/BRA would not be significantly changed because none of the other mobile contaminants has a risk or hazard index high enough that a factor of 2 increase would cause them to exceed screening thresholds (i.e., risk greater than or equal to 1E-05 or hazard index greater than or equal to 1).

6.5.3.2.3 ***Reduced Infiltration Inside the Subsurface Disposal Area***—A reduced infiltration sensitivity case was performed to evaluate groundwater ingestion risk if infiltration inside the SDA was reduced from the current average of 5 to 0.1 cm/year. This is the opposite extreme from the high-infiltration sensitivity case presented in the next subsection. The 0.1-cm/year infiltration rate is equivalent to return of the system to a low natural background infiltration rate or to installing a surface barrier in the SDA. Figure 6-100 shows that the peak groundwater ingestion risk from radionuclides is reduced from 3E-04 to 2E-04 if Tc-99 and I-129 are included in the total. When Tc-99 and I-129 are excluded from the total, the peak risk goes from 3E-04 to 7E-06.

Reduced infiltration inside the SDA reduces contaminant transport into the subsurface, especially for dissolved-phase contaminants. The risk or hazard index is correspondingly lower, and timing of the peak risk or hazard index changes.
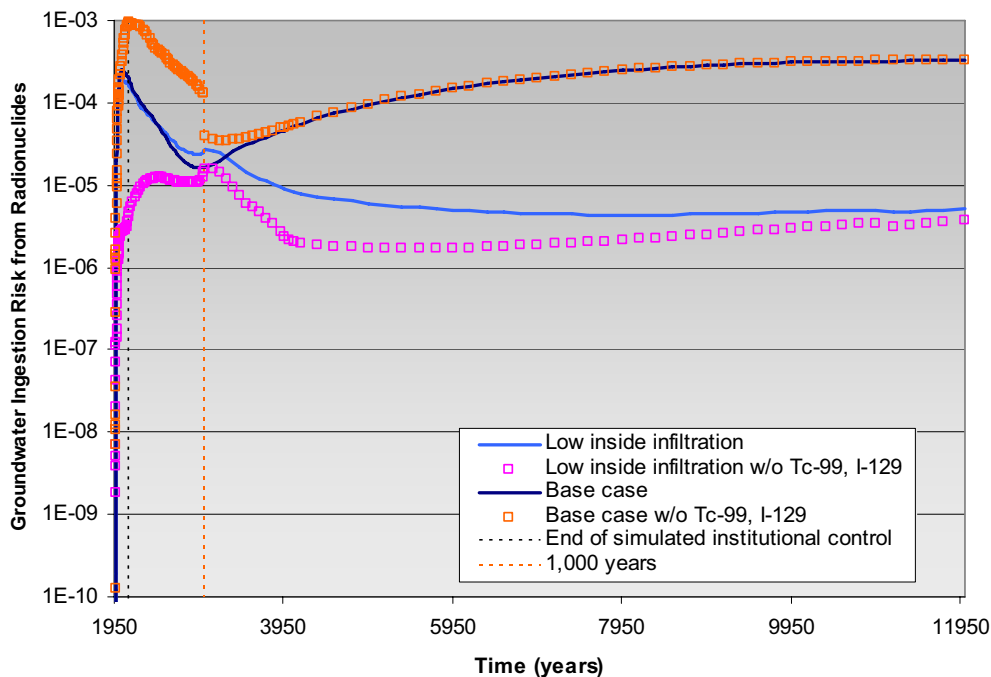
Figure 6-100. Reduced infiltration sensitivity case (peak groundwater ingestion) inside the Subsurface Disposal Area, with and without technetium-99 and iodine-129.

6.5.3.2.4 **High Infiltration Inside the Subsurface Disposal Area**—To assess the effect of maximum infiltration, additional simulations were run using total average annual precipitation for comparison to spatially variable infiltration used in the base case. Results are presented in Figures 6-101 through 6-104, which show that increased infiltration increases peak risk and causes the peak to occur sooner, both for dissolved-phase flow and dual-phase flow. The net average infiltration for the base case is 5 cm/year. The sensitivity case simulates an extreme maximum infiltration—uniform infiltration of the total annual precipitation (i.e., 23 cm/year) throughout the simulation period is applied. This higher infiltration is equivalent to completely neglecting evapotranspiration, which is known to be significant in the semiarid environment at the INL Site.

Substantially increased infiltration inside the SDA produces a major effect by increasing risk and causing the peak to occur much earlier. Total groundwater ingestion risk is shown in Figure 6-101. Risks shown before the year 2110, during the simulated 100-year institutional control period, are shown only to compare the effect of varying infiltration rates. Together, Np-237 and U-238 drive the risk with peak values of 2E-04, each, for this extreme infiltration case. Peak risk for the mobile contaminants increases as well. Technetium-99 risks are shown in Figure 6-102. The Tc-99 groundwater ingestion peak risk increases from 1.9E-04 to 2.4E-04. Because Tc-99 simulations do not match measured values (see Section 5.2.5), nitrate is shown as an alternative example in Figure 6-103. Both Tc-99 and nitrate are dissolved-phase contaminants. The high-infiltration case for nitrate peaks higher and earlier than the base case, and the groundwater ingestion hazard quotient drops below 1 faster. Figure 6-104 shows C-14 as representative of dual-phase flow. Carbon-14 was chosen for evaluation rather than other VOCs to eliminate the complication of accounting for the vapor vacuum extraction system currently operated by the OCVZ Project. For the high-infiltration sensitivity case, the peak groundwater ingestion risk for C-14 increases from 1E-05 to nearly 5E-05.
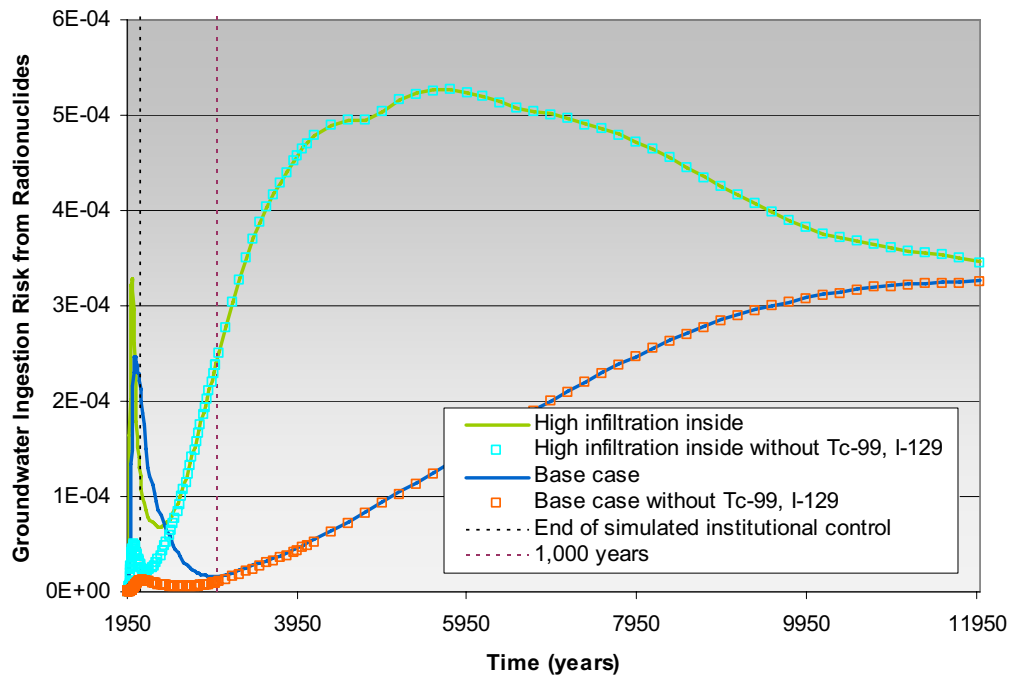
Figure 6-101. High infiltration inside the Subsurface Disposal Area sensitivity case shown on a detailed risk scale, with and without technetium-99 and iodine-129.
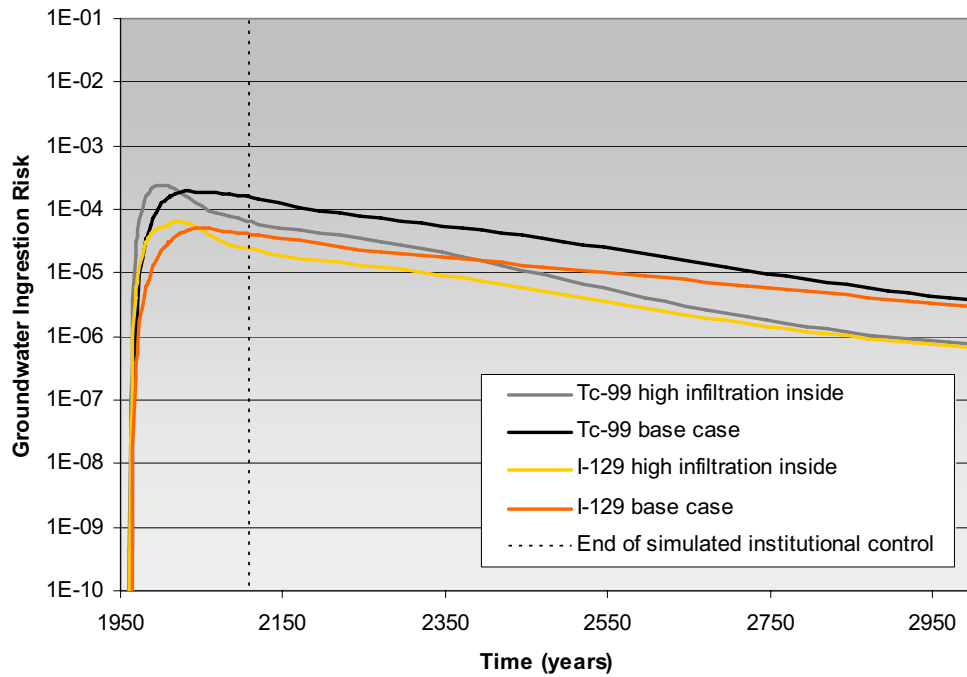
Figure 6-102. Comparison of estimated technetium-99 and iodine-129 groundwater ingestion risk for the sensitivity case of high infiltration inside the Subsurface Disposal Area.
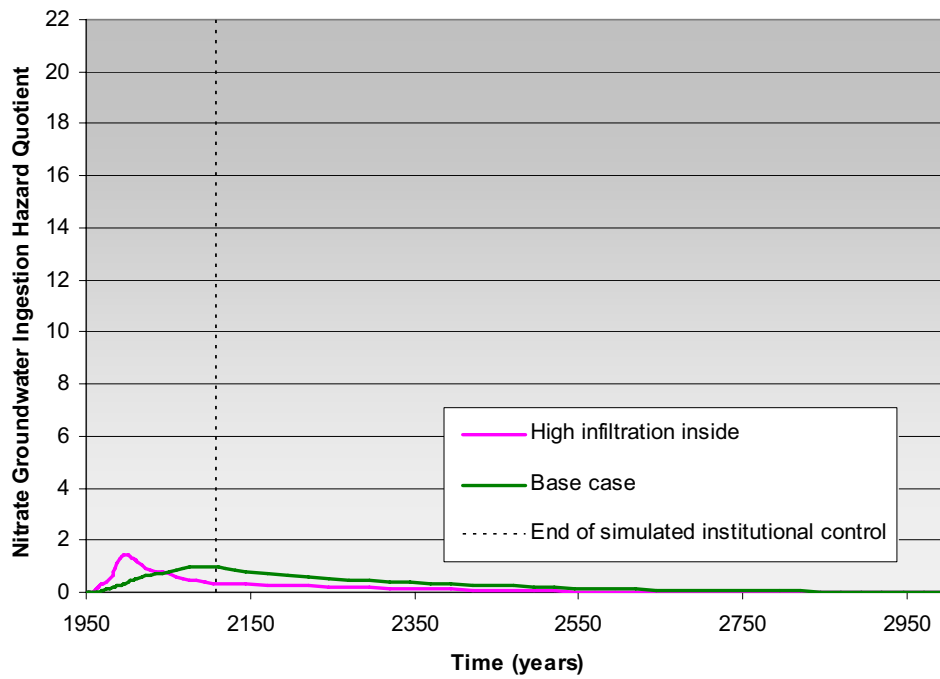
Figure 6-103. Comparison of estimated nitrate groundwater ingestion hazard quotient for the sensitivity case of high infiltration inside the Subsurface Disposal Area.
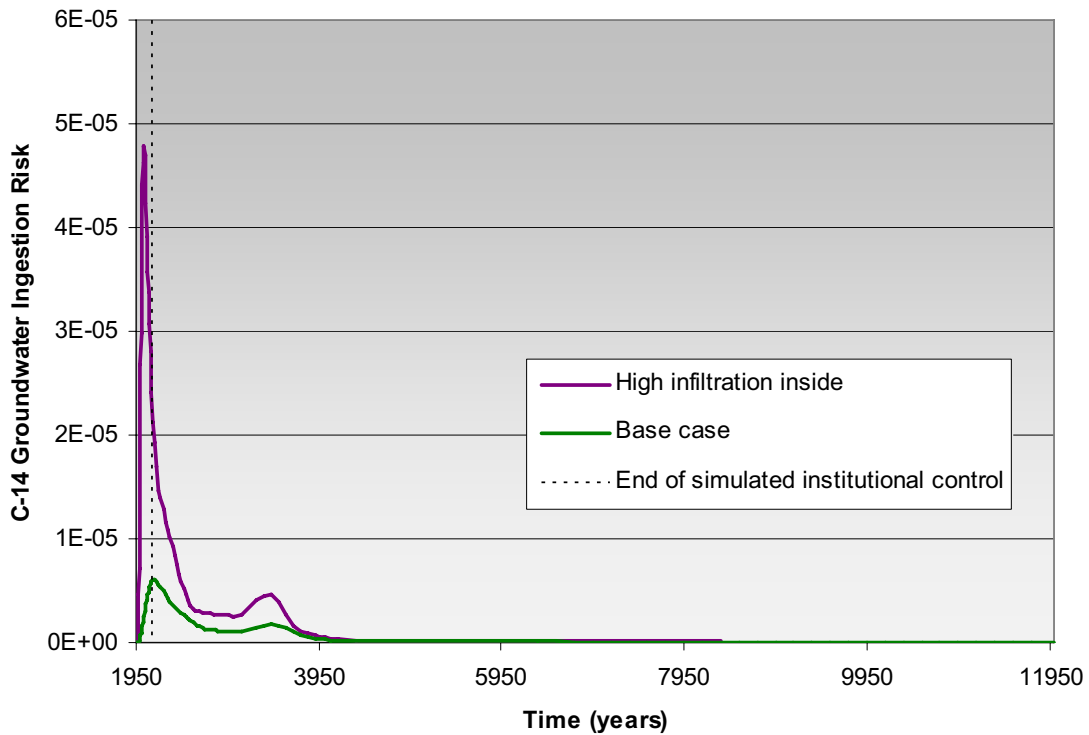
Figure 6-104. Comparison of estimated carbon-14 groundwater ingestion risk for the sensitivity case of high infiltration inside the Subsurface Disposal Area.

Though this sensitivity case presents an extreme situation, it demonstrates the influence of infiltration rates through buried waste on the magnitude and timing of peak risk—higher infiltration through the waste generates higher, earlier risks. Conversely, as shown in Section 6.5.3.2.2, higher infiltration outside the SDA tends to reduce risk. Acknowledged sensitivity to infiltrations rates is one reason DOE, DEQ, and EPA identified both 1,000-year and 10,000-year simulation periods for groundwater.

6.5.3.2.5   *Gaps in the B-C Interbed*—Gaps are known to exist in the B-C interbed. To assess the potential effect of these gaps on overall risk, the complete absence of the B-C interbed was simulated and compared to the base case. The base case used kriged lithology (Leecaster 2004) that addresses interbeds of variable thicknesses with some very thin areas, but with no actual gaps. Results are presented in Figures 6-105 through 6-107. Risks before the year 2110, during the simulated 100-year institutional control period, are shown only to compare the effect of variation on the B-C interbed. Exposure to contaminated groundwater at the INL Site would be prevented during the simulated 100-year institutional control period.

Figure 6-105 shows a change in the time and value of the peak total groundwater ingestion risk. The peak increases from 3E-04 to 7E-04 and moves from the year 12000 to the year 8350. The Tc-99 groundwater ingestion risk increases from 1.9E-04 to 2.7E-04. Because Tc-99 simulations do not match measured concentrations (see Section 5.2.5), nitrate is shown as an alternative example in Figure 6-107. The nitrate hazard quotient shows less effect than the Tc-99 or total risk plots. The peak groundwater ingestion hazard quotient changes by only 2%.
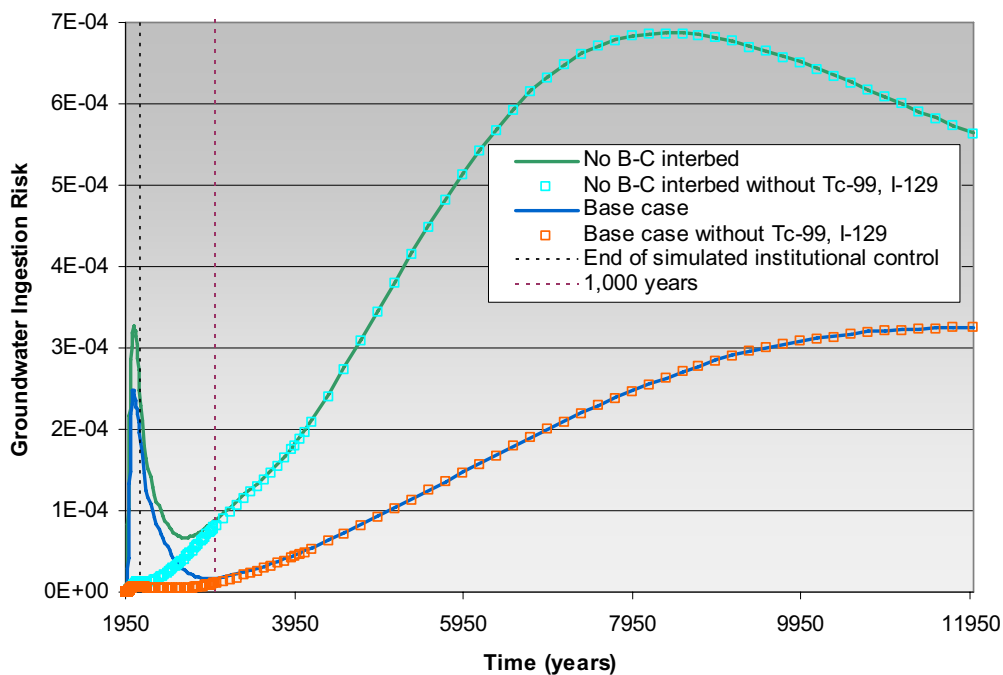
Figure 6-105. No B-C interbed sensitivity case (groundwater ingestion risk), with and without technetium-99 and iodine-129.
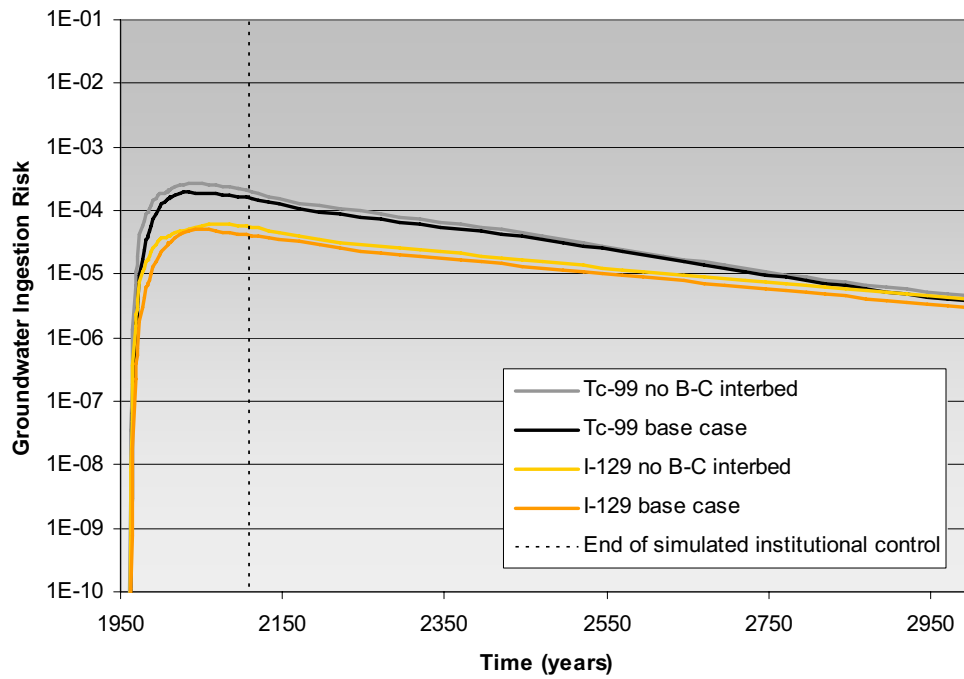
Figure 6-106. Comparison of estimated technetium-99 and iodine-99 groundwater ingestion risk for the B-C interbed gaps sensitivity case.
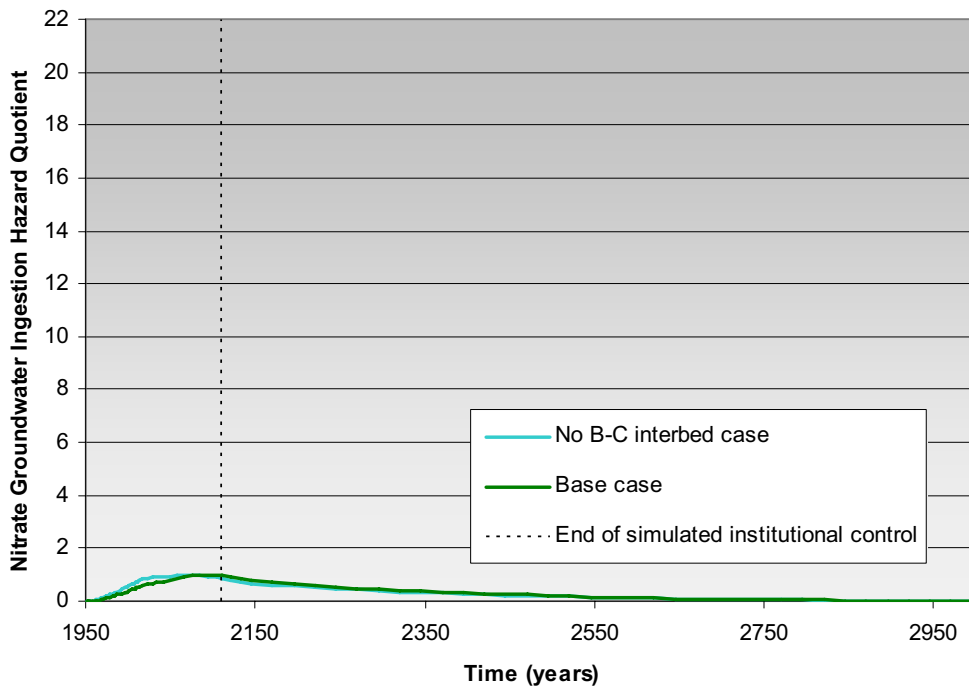
Figure 6-107. Comparison of estimated nitrate groundwater ingestion hazard quotient for the B-C interbed gaps sensitivity case.

Complete absence of the B-C interbed would increase risk roughly by a factor of 2, which would not substantially change conclusions for the RI/BRA. Gaps in the interbeds would have much less effect than complete absence of an interbed. Furthermore, deeper interbeds, though known to exist, are not simulated because data are not sufficient to parameterize them. Omitting these deeper interbeds produces higher risk estimates.

6.5.3.2.6   *No Retrieval or Grouting*—The base case accounts for completed grouting of most beryllium blocks buried in the SDA (Lopez et al. 2005) and the anticipated completion of the Accelerated Retrieval Project in Pit 4 (DOE-ID 2004). To simplify modeling, both actions were assumed to occur in 2004, a date that is appropriate for completed grouting, but that may not be conservative for the ongoing retrieval. Figure 6-108 shows the effect from radionuclides on total groundwater ingestion risk, both with and without Tc-99 and I-129, if neither remedial action occurred. As the figure shows, the net effect is small. The peak risk increases from 3.3E-04 in the base case to 3.4E-04 without the limited Pit 4 retrieval or grouting.
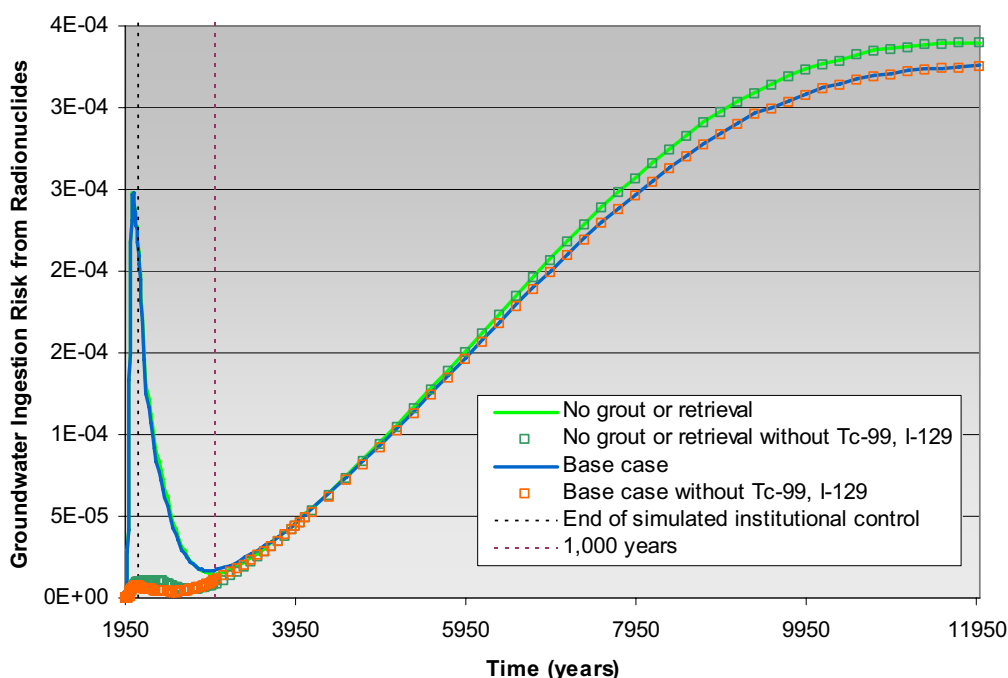
Figure 6-108. Comparison of groundwater ingestion risk on a detailed scale for the no-grout and no-retrieval sensitivity case, with and without technetium-99 and iodine-129.

Risk from Tc-99 and C-14 was affected by grouting beryllium blocks. Figure 6-109 shows that groundwater ingestion risk from Tc-99 or I-129 does not change in the absence of no grouting or retrieval. Figure 6-110 shows a minor change to groundwater ingestion risk for C-14 because of grouting. Uranium and VOCs are targeted for retrieval in the Accelerated Retrieval Project. Figure 6-111 shows no change to U-238 groundwater ingestion risk without retrieval. Figure 6-112 shows no change to the VOC groundwater ingestion risk without retrieval. Figure 6-113 shows the comparison of surface exposure pathway risk for the no-retrieval sensitivity case, with and without retrieval. The net impact on risk is small for all contaminants because inventory targeted by retrieval is a small fraction of the total inventory.
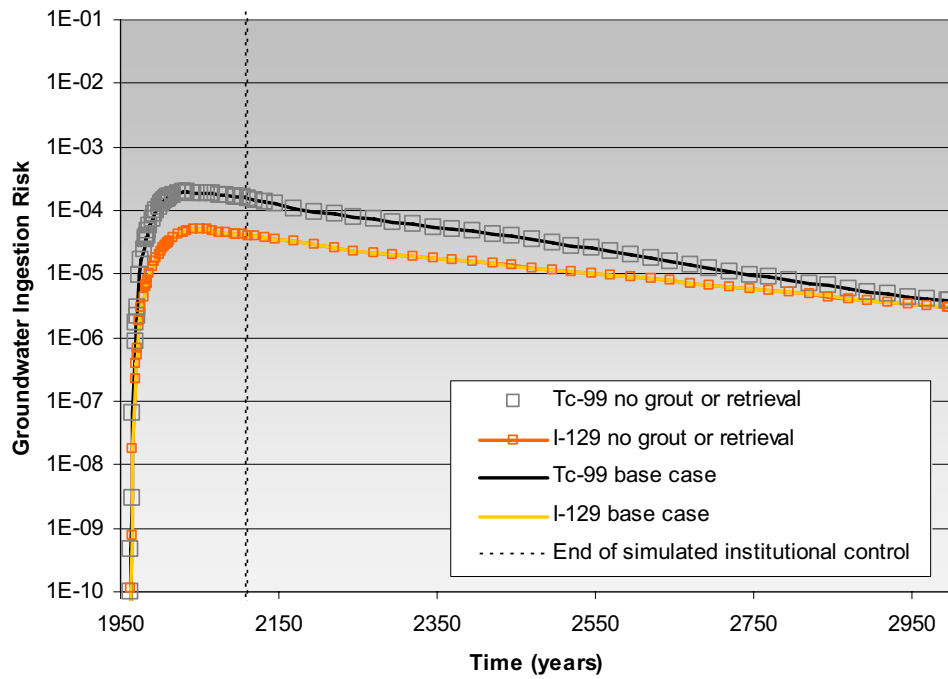
Figure 6-109. Comparison of estimated technetium-99 and iodine-129 groundwater ingestion risk for the no-grout and no-retrieval sensitivity case.
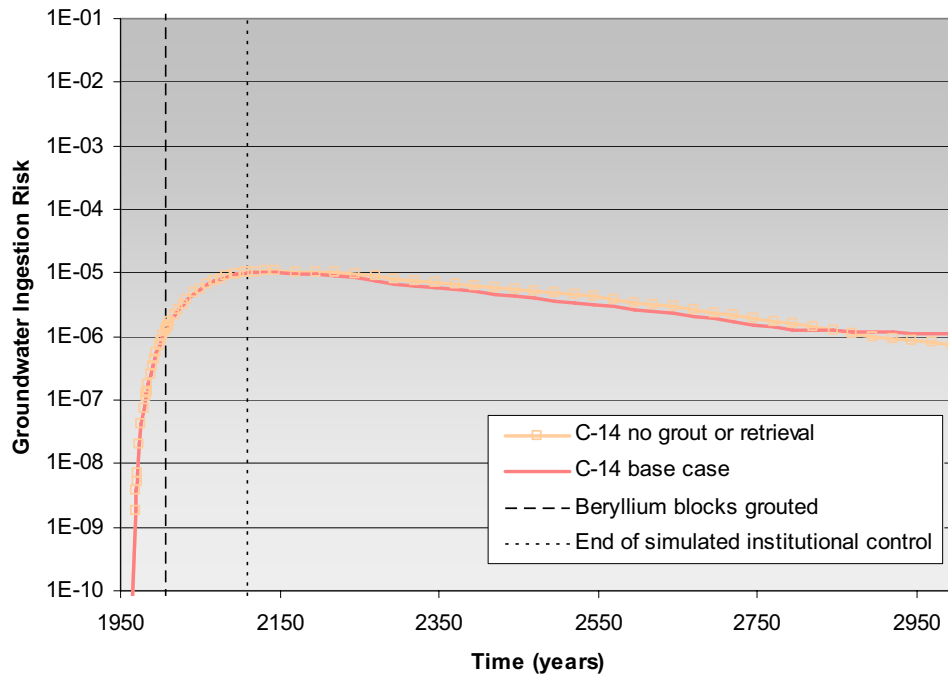
Figure 6-110. Comparison of estimated carbon-14 groundwater ingestion risk for the no-grout and no-retrieval sensitivity case.

6-128
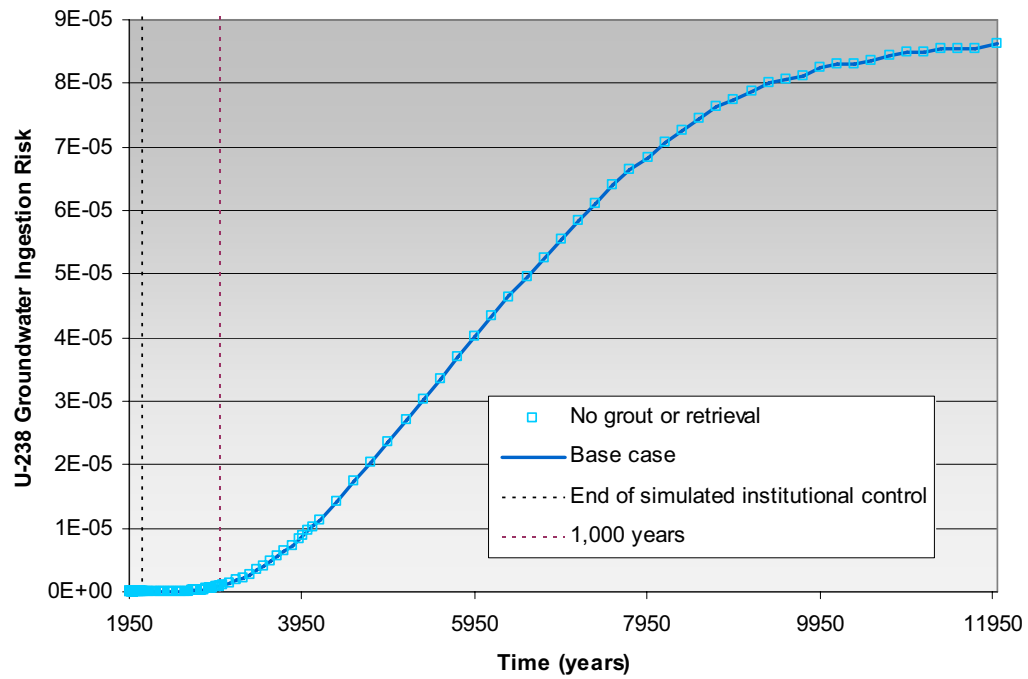
Figure 6-111. Comparison of estimated uranium-238 groundwater ingestion risk for the no-grout and no-retrieval sensitivity case.
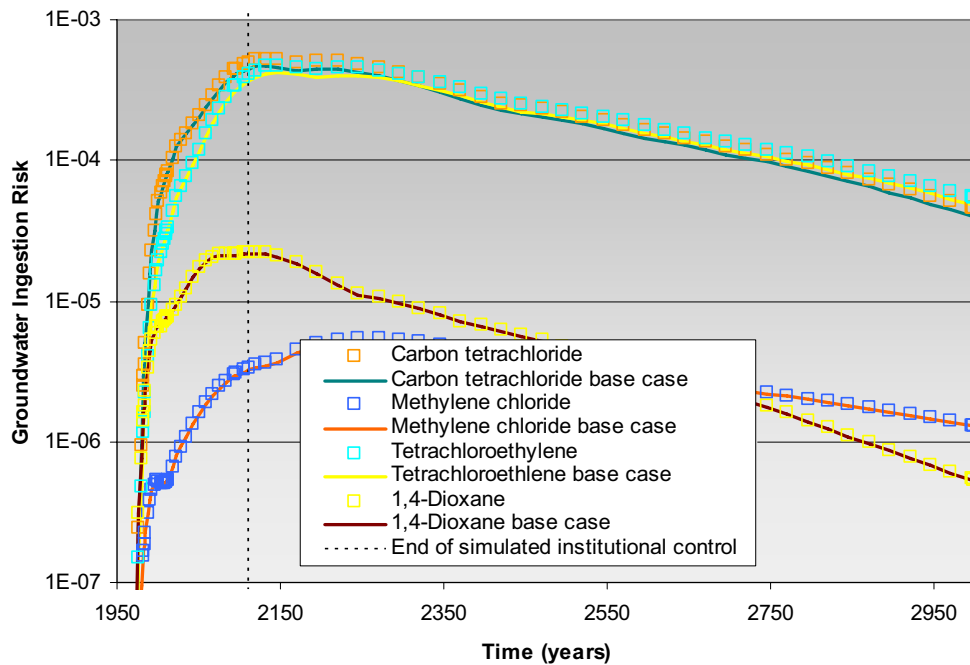
Figure 6-112. Groundwater ingestion risk for the no-retrieval and no-grout sensitivity case.
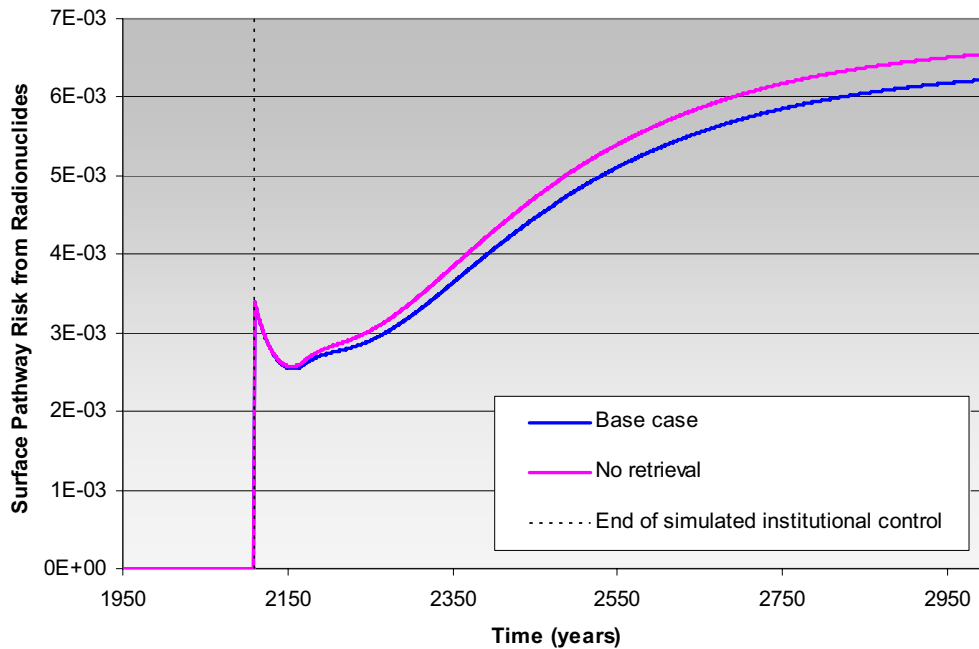
Figure 6-113. Comparison of surface exposure pathway risk for the no-retrieval sensitivity case.

6.5.3.2.7 No Low-Permeability Zone beneath the Subsurface Disposal Area—

The base case accounts for the measured low-permeability zone beneath the SDA. This zone means less water mixes with contaminants entering the aquifer from the SDA. Full extent of the low-flow zone is not completely known. To address the effect of this zone on risk results, a sensitivity case was run using a permeability of 712,000 mD, which is more typical of the Snake River Plain Aquifer than the value of 153 mD used in the base-case simulations (see Figure 6-114). Risks shown before the year 2110 are for comparison purposes only because institutional controls would preclude exposure. Figure 6-115 illustrates total groundwater ingestion risk for radionuclides. The risk drops nearly an order of magnitude from 3E-04 to 4E-05 for long-term risk without Tc-99 and I-129. Individual contaminants would show similar results. Figure 6-116 shows groundwater ingestion risk for carbon tetrachloride. Peak groundwater ingestion risk for the no low-permeability sensitivity case demonstrates that base-case results are conservative by as much as a factor of 4.
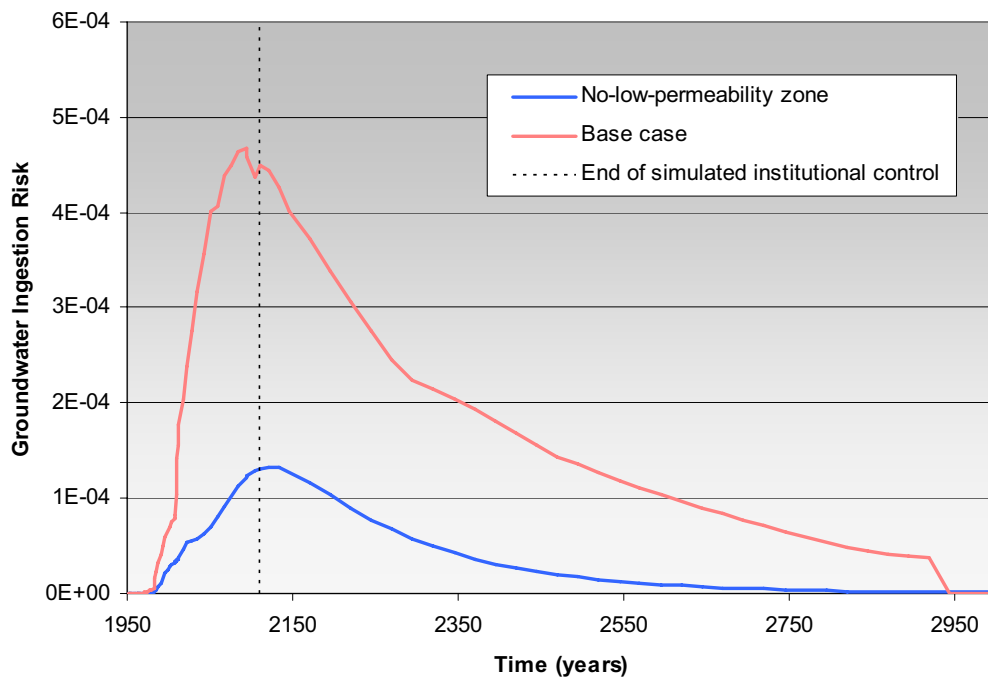
Figure 6-114. Radionuclide groundwater ingestion risk for the no-low-permeability zone sensitivity case.
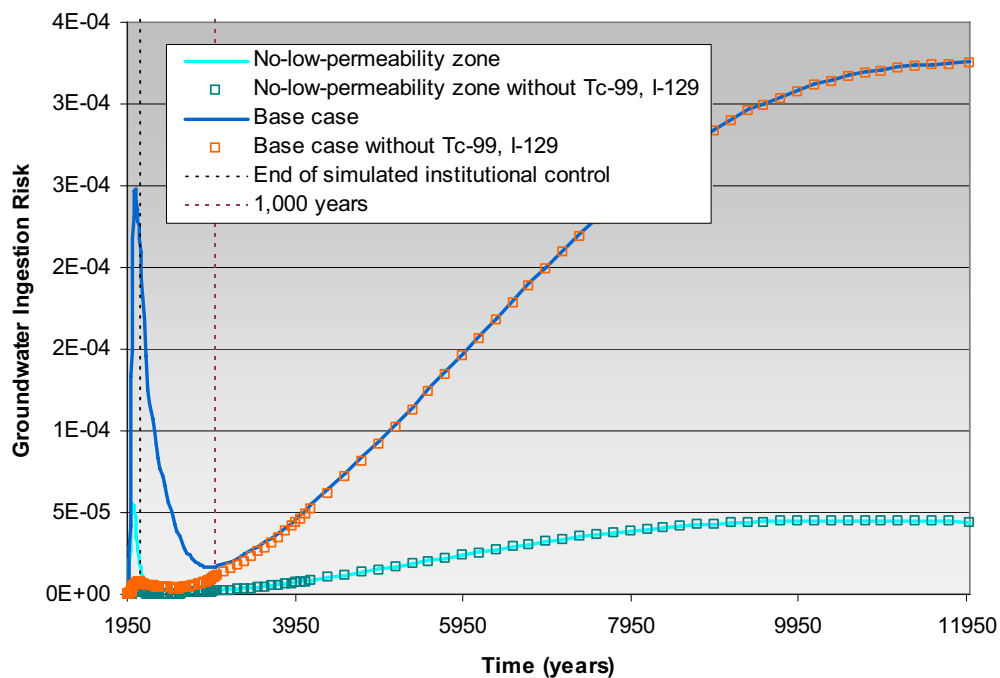
Figure 6-115. Total groundwater ingestion risk for the no-low-permeability zone sensitivity case, with and without technetium-99 and iodine-129.
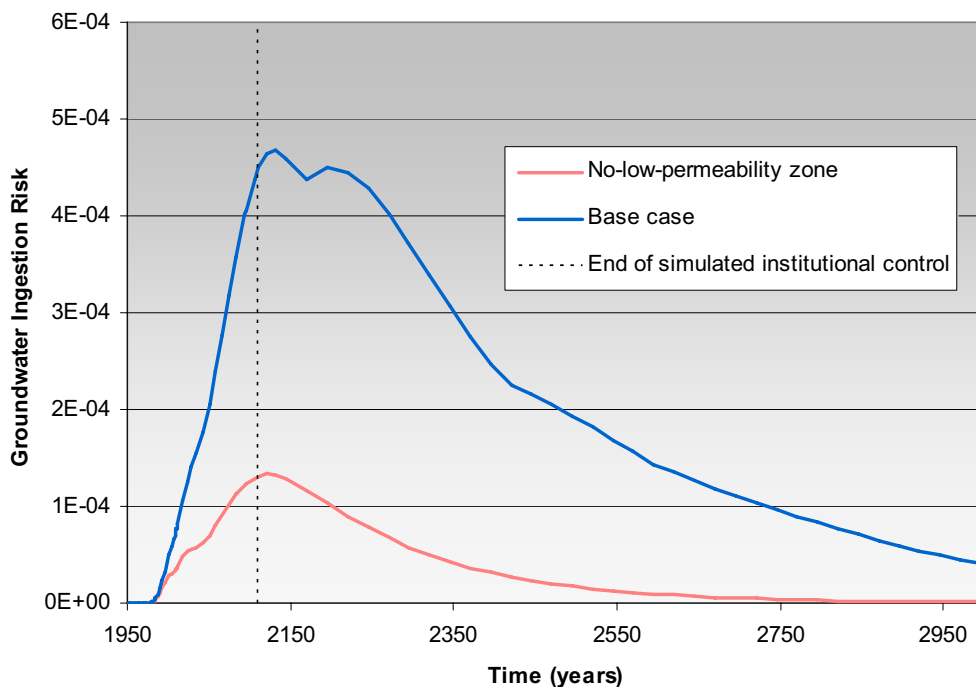
Figure 6-116. Carbon tetrachloride groundwater ingestion risk for the no-low-permeability zone sensitivity case.

6.5.3.2.8   *Sorption in Vadose Zone Interbeds*—In the RI/BRA base case, a hypothetical mobile fraction of Pu-239 and -240 inventories moves through surficial sediment and the A-B interbed without sorption. Sorption occurs in the base case in the deeper, nearly continuous B-C and C-D interbeds. The extreme bounding sensitivity case presented below completely eliminates sorption of plutonium in the deeper and more continuous B-C and C-D interbeds. Advective spreading during transit of the vadose zone results in some dilution because contaminant flux is more widely spread as it enters the aquifer model domain.

Figure 6-117 compares the base case to groundwater ingestion risks at the INL Site boundary for Pu-239 without sorption. Figure 6-118 shows a similar plot for Pu-240. For both isotopes, the risk is orders of magnitude higher than the base-case risk. Section 5.2.5.3.3 compares simulated Pu-239 concentrations to measured concentrations. Concentrations predicted by this sensitivity case are orders of magnitude higher than have been detected. This sensitivity case is extremely conservative because it is roughly equivalent to spreading the plutonium source term into a thin layer and leaching it directly into the aquifer.
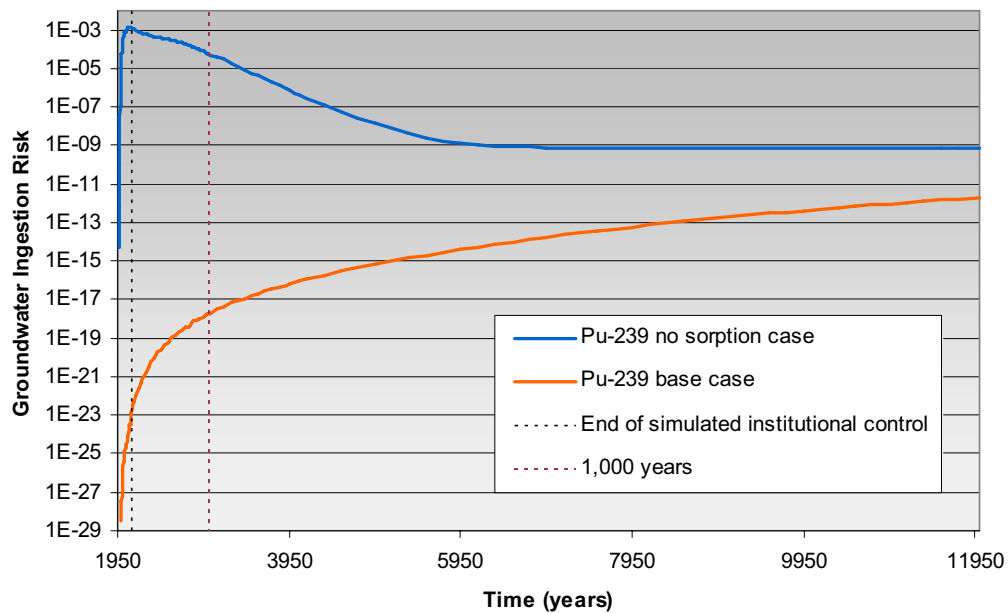
Figure 6-117. Groundwater ingestion risk at the southern boundary of the Idaho National Laboratory Site for the no-sorption sensitivity case compared to the base case for plutonium-239.
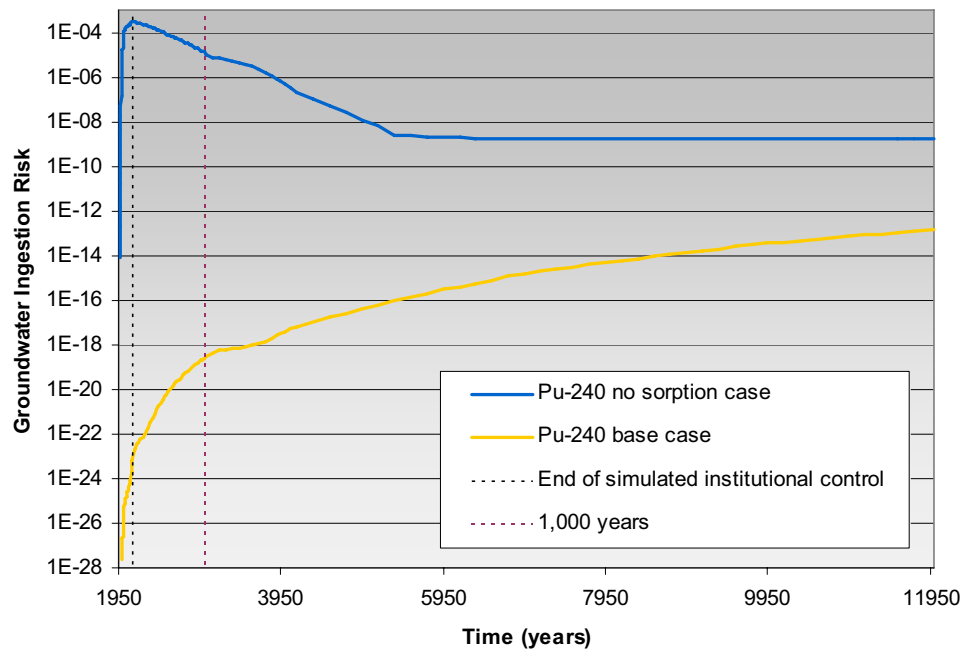
Figure 6-118. Groundwater ingestion risk at the southern boundary of the Idaho National Laboratory Site for the no-sorption sensitivity case compared to the base case for plutonium-240.

6.6   Inadvertent Intruder Analysis

Previous risk assessments (Becker et al. 1998; Holdren et al. 2002) address the inadvertent intruder scenario with a qualitative analysis, as specified in the original Work Plan (Becker et al. 1996) and the First Addendum to the Work Plan (DOE-ID 1998). For this remedial investigation, a quantitative analysis was specified. The scenario was defined in the Second Addendum (Holdren and Broomfield 2004) as an inadvertent intruder represented by a well driller completing an agricultural well through the buried waste. Figure 6-119 shows the conceptual model for the scenario. The driller would incur acute (i.e., short-term) exposure to drill cuttings brought to the surface.

Because different contaminants have different effects, two locations representing two types of radioactivity (i.e., alpha and gamma) were identified for the hypothetical well. Dust generated by drilling operations could pose a health risk because alpha radiation is harmful if inhaled. In addition to inhalation issues, gamma radiation can cause a dose from direct exposure. The following subsections discuss how specific locations in the SDA were chosen for the two scenarios.
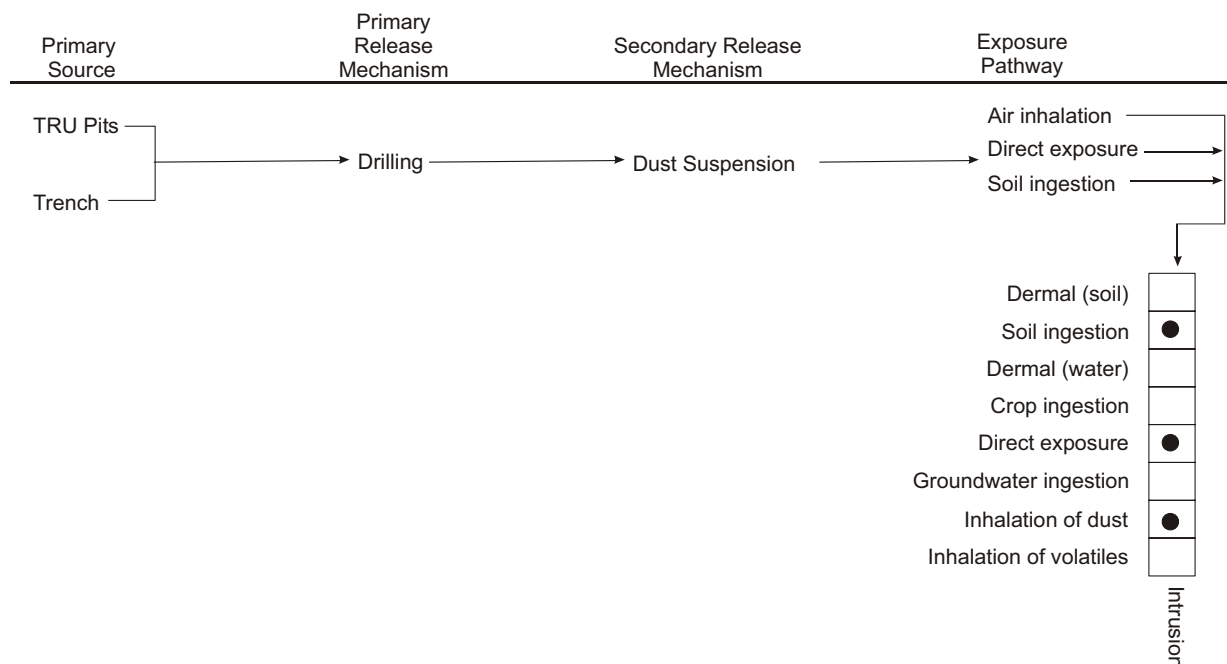
Figure 6-119. Conceptual model for the inadvertent intruder scenario represented by a well driller completing an agricultural well through buried waste.

6.6.1   Locations for the Intruder Scenario

This subsection discusses the methodology and the locations and inventories selected for high-alpha and high-gamma acute scenarios represented by a well driller (i.e., intruder).

6.6.1.1 **_High-Alpha Scenario._** The following methodology was used to determine the location of the high-alpha intruder scenario. First, the major risk pathway was determined to be from inhaling dust produced by drilling. Waste forms that most easily would generate respirable particles are graphite and high-efficiency particulate air filters from Rocky Flats Plant waste. The location of the highest curie density was determined using the Waste Inventory Location Database. A large number of high-efficiency particulate air filters came from shipments RFODOWSR107/02/63800 and RFODOWSR107/02/63810, which overlap to provide a high density of alpha-emitting waste. The calculated density is 14.4 Ci/ft^2. Table 6-14 provides the location and curie breakdown, while Figure 6-120 shows the identified location.

Table 6-14. Total curies in selected high-alpha shipments and relative amounts of each isotope for the intruder scenario.

Radionuclide	Inventory (Ci)	Relative Fraction
Am-241	189	0.09
Pu-239	1,582	0.74
Pu-240	351	0.17
Total	**2,122**	**1.00**
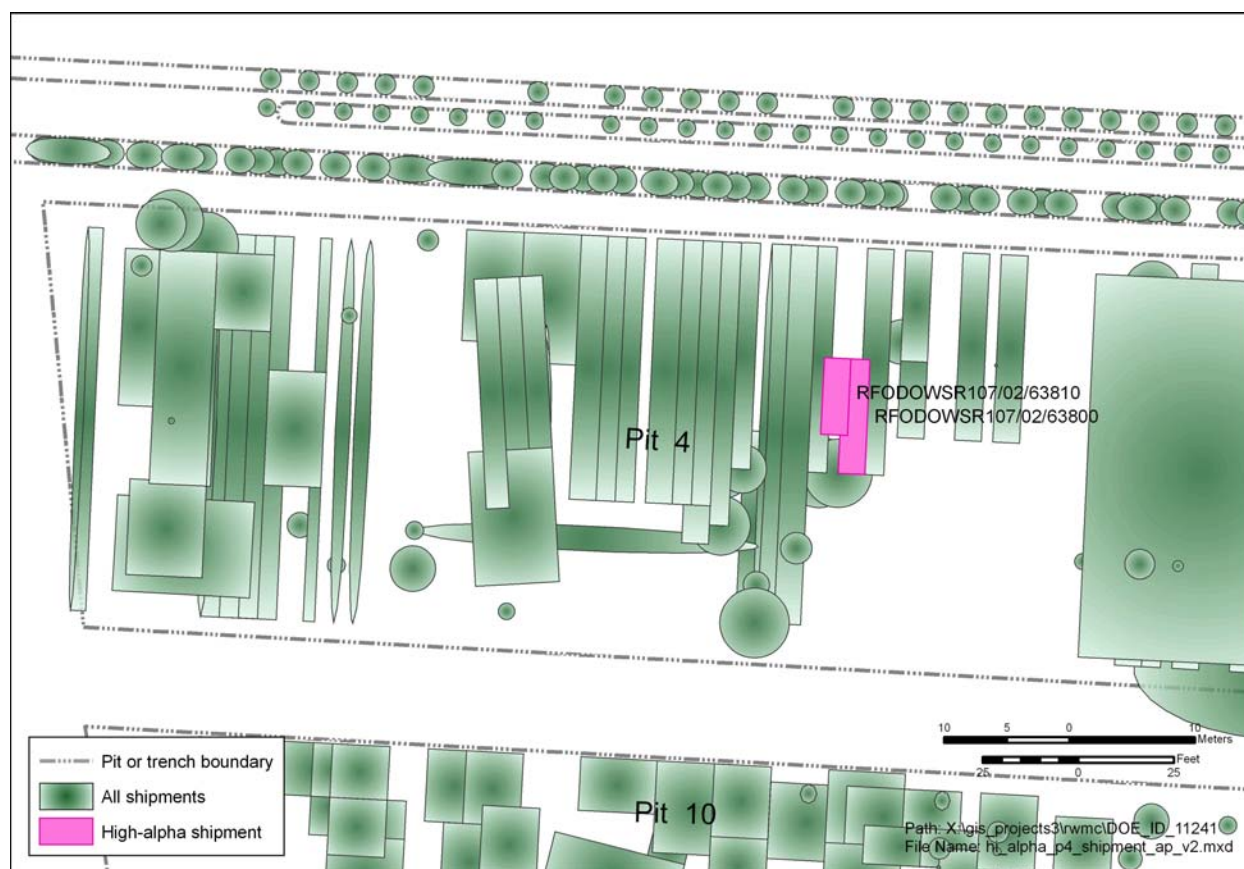
Figure 6-120. Location and breakdown of high-alpha waste for the intruder scenario.

6.6.1.2 **_High-Gamma Scenario._** To determine the location for the high-gamma intruder scenario, the Waste Information and Location Database was queried for all shipments with gamma-emitting nuclides (i.e., Nb-94, Cs-137, Co-60, and Sr-90). Because these isotopes have relatively short half-lives, curie amounts were decayed until the year 2110 and multiplied by their respective external exposure slope factor to provide relative risk values. Risk values were summed by location to identify the location with the highest total relative risk for input into the intruder scenario. The year 2110 was chosen because it represents the end of simulated active institutional control. Later timeframes would pose less risk because of radioactive decay.

This methodology yielded a list of possible locations for the high-gamma intruder scenario. Table 6-15 shows shipment descriptions for five locations with the highest relative risk. Review showed that several shipments in the first four locations would not be conducive to drilling. Those shipments contain large chunks of concrete or steel through which it would be difficult to drill. Table 6-15 lists the top five scoring locations and identifies the fifth location (i.e., Trench 42 at 0 + 50 ft) for the scenario.

Because shipments on both sides overlapped the identified location, curies from adjacent shipments were used to evaluate total curies for this scenario. The shipment area is 5.2 m^2 (56 ft^2). Because the borehole is 56 cm (22 in.) in diameter, only a fraction of total shipment (i.e., 0.047 Ci) will be brought to the surface. Table 6-16 provides total inventory to be used in the high-gamma intruder scenario. Figure 6-121 shows the location of high-gamma shipments used for the intruder scenario.

Table 6-15. Evaluation and selection of a high-gamma location for the intruder scenario.

Top 10	Disposal Date	Location	Document Identifier	Shipment Description
1	6/5/1961	Pit 2	OFFATISR104/26/61800200	(1) 136 55-gal steel drums of compressed dry waste covered with concrete cap and steel lid
				(2) 4 55-gal drums, similar to the above, except containing a lead cask surrounded by concrete
				(3) 2 55-gal drums containing a lead cask surrounded on all sides with concrete
				(4) 55 conduits in two sizes (3 ft diameter × 4 ft tall and 4 ft diameter × 4 ft tall) containing a 30-gal drum or other primary container surrounded by concrete
				(5) 1 wooden box (146 × 37 × 37 in.) containing a wash trough centered in the box and surrounded by reinforced concrete
				(6) 2 55-gal drums packaged similar to (1), except contents are solidified liquid waste
				(7) 8 55-gal drums with permanent lids containing bungs filled with solidified liquid waste
				(8) 33 55-gal drums of same type as (6) and containing solidified liquid waste
				(9) 181 55-gal drums containing compressed dry waste
				(10) 20 wooden containers containing dry waste (mixed fission products = 25.41 Ci)
1	6/5/1961	Pit 2	OFFATISR104/26/6181020022	(1) 31 55-gal steel drums containing a lead cask surrounded by concrete
				(2) 6 55-gal drums containing a lead cask surrounded by concrete
				(3) 11 conduits in multiple sizes (one 3 ft diameter × 3 ft tall, four 3 ft diameter × 4 ft tall, and six 4 ft diameter × 4 ft tall) containing a 30-gal drum or other primary container enclosed in concrete (mixed fission product = 11,533.58 Ci)
2	8/14/1963	Trench 30	CFA669SR008/14/63810	Sewer waste (unknown isotopes = 3 Ci)
2	8/19/1963	Trench 30	PERAIISR008/16/63800	Wood, rags, steel, and cardboard (unknown isotopes = 0.005 Ci)
2	8/13/1963	Trench 30	TRA603SR008/13/63800	Cardboard boxes containing miscellaneous trash (e.g., metal, wood, and paper) (unknown isotopes = 0.001 Ci)
2	8/2/1963	Trench 30	TRA642SR008/02/63800	18 cardboard boxes containing routine hot waste (unknown isotopes = 0.3 Ci)
2	8/2/1963	Trench 30	TRA642SR008/02/63810	18 cardboard boxes containing routine hot waste (unknown isotope = 0.96 Ci)
2	8/7/1963	Trench 30	TRA642SR008/06/63810	Cask insert with a stainless steel basket containing corrosion products in resin (100,000 Ci)
3	6/20/1963	Trench 30	ANL601SR006/26/63810	Cardboard boxes containing miscellaneous debris (e.g., wire, paper, and plastic) (unknown isotopes = 0.008 Ci)
3	7/2/1963	Trench 30	NRF618SR007/02/63800	10 cardboard boxes containing miscellaneous contaminated scrap from a dumpster
3	7/1/1963	Trench 30	TRA603SR007/01/63800	Canal trash basket insert containing cobalt slugs, end boxes, and miscellaneous trash
3	5/29/1963	Trench 30	TRA642SR004/29/63800	Cask insert containing corrosion products
4	2/18/1988	SVR 14	ANL76502/18/883448	Core subassembly parts

Table 6-15. (continued).

Top 10	Disposal Date	Location	Document Identifier	Shipment Description
4	2/25/1988	SVR 14	ANL78502/25/883455	Core subassembly parts
4	3/4/1988	SVR 14	ANL78503/04/883463	Core subassembly parts
5	7/19/1966	Trench 42	CPP601SR007/19/661101	1 3-gal-can (insert) containing glass (mixed fission products = 1,200 Ci)
5	7/21/1966	Trench 42	CPP601SR007/20/661904101	1 3-gal-can (insert) containing glass (mixed fission products = 1,900 Ci)
5	7/22/1966	Trench 42	CPP601SR007/22/661101	1 3-gal-can (insert) containing glass (mixed fission products = 1,000 Ci)
5	7/26/1966	Trench 42	CPP601SR007/26/662101	1 3-gal-can (insert) containing glass (mixed fission products = 1,200 Ci)
5	8/5/1966	Trench 42	CPP601SR008/05/661102	1 lead cask (insert) containing leached Vycor glass (100 Ci)
5	9/6/1966	Trench 42	NRF617SR009/06/66200	18 2 × 2 × 3-ft cardboard boxes containing miscellaneous trash (e.g., blotting paper, paper, rags, and swipes) (Co-60 < 0.00002 Ci)
5	7/14/1966	Trench 42	CPP601SR007/14/661101 (overlapping shipment)	1 3-gal can (insert) containing glass (mixed fission products = 1,500 Ci)
5	7/27/1966	Trench 42	CPP601SR007/27/661101 (overlapping shipment)	1 3-gal can (insert) containing glass (mixed fission products isotope = 1,000 Ci)
5	7/28/1966	Trench 42	CPP601SR007/28/661906101 (overlapping shipment)	1 lead cask (insert) containing leached Vycor glass (mixed fission products = 2,000 Ci)
5	8/03/1966	Trench 42	CPP601SR008/03/661102 (overlapping shipment)	1 lead cask (insert) containing leached Vycor glass (200 Ci)
5	8/04/1966	Trench 42	CPP601SR008/04/661102 (overlapping shipment)	1 lead cask (insert) containing leached Vycor glass (200 Ci)

Location selected for intruder analysis.

Table 6-16. Curies in high-gamma shipments decayed to the year 2110.

Isotope	Total Amount in All Identified Shipments	Fraction in Well Decayed to the Year 2110	Isotope	Total Amount in All Identified Shipments	Fraction in Well Decayed to the Year 2110
Ac-227	1.17E-08	5.67E-12	Pu-238	4.38E-03	6.61E-05
Am-241	4.4E-06	1.66E-07	Pu-239	1.79E-01	8.40E-03
Am-243	1.36E-12	6.31E-14	Pu-240	1.36E-03	6.30E-05
Be-10	3.58E-07	1.68E-08	Pu-241	8.02E-04	3.69E-08
C-14	1.42E-05	6.57E-07	Pu-242	3.33E-11	1.57E-12
Cm-243	3.27E-12	4.64E-15	Pu-244	3.89E-22	1.83E-23
Cm-244	6.78E-13	1.29E-16	Ra-226	2.03E-09	9.01E-11
Cm-245	1.73E-18	8.05E-20	Ra-228	1.29E-14	1.77E-23
Cm-246	9.87E-22	4.55E-23	Sr-90	1.05E+04	1.51E+01
Co-60	1.52E-05	4.26E-15	Tc-99	1.66E+00	7.85E-02
Cs-137	1.17E-04	2.03E+01	Th-228	8.63E-06	8.21E-30
Eu-152	6.17E-02	1.60E-06	Th-229	2.47E-10	1.15E-11
Eu-154	9.87E+00	5.52E-06	Th-230	2.34E-06	1.10E-07
Tritium	8.63E-01	1.30E-03	Th-232	8.02E-14	3.78E-15
I-129	4.50E-03	2.12E-04	U-232	1.23E-05	1.45E-07
Nb-94	2.10E-06	9.85E-08	U-233	4.75E-07	2.24E-08
Ni-59	4.56E-08	2.15E-09	U-234	6.78E-02	3.20E-03
Ni-63	2.42E-06	4.04E-08	U-235	2.28E-03	1.08E-04
Np-237	3.33E-05	1.57E-06	U-236	4.44E-04	2.09E-05
Pa-231	1.91E-07	8.99E-09	U-238	3.21E-04	1.51E-05
Pb-210	8.02E-11	4.30E-14			
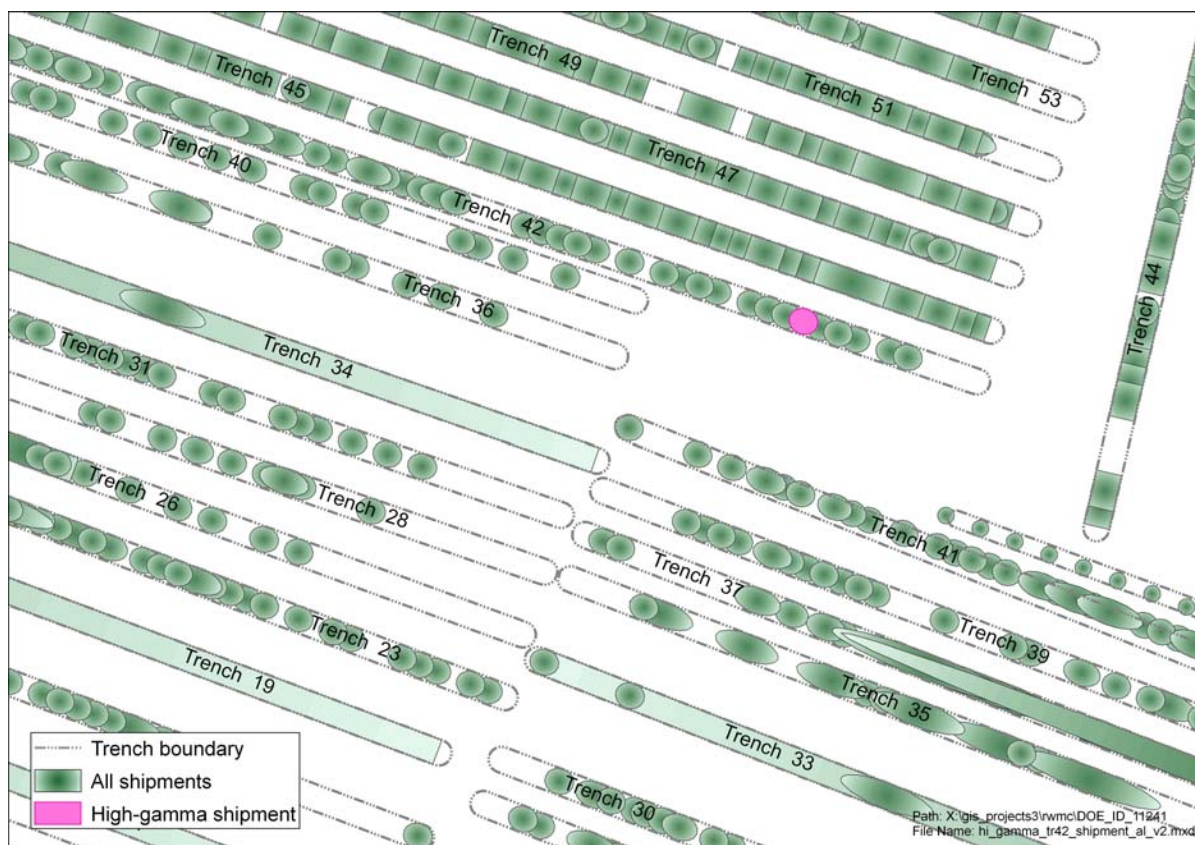
Figure 6-121. Location of high-gamma shipments used for the intruder scenario.

6.6.2 Intruder Scenario Assessment

The intruder assessment is based on a hypothetical acute exposure to radioactive waste while drilling an irrigation well (Holdren and Broomfield 2004). The acute exposure scenario incorporates the assumption that an inadvertent intruder drills a large-diameter (i.e., 56 cm [22 in.]) irrigation well directly into waste disposal units in the SDA. One high-gamma and one high-alpha location each were evaluated. The intruder is assumed to be exposed to contaminated drill cuttings brought to the surface and spread over the ground. Exposure pathways for this acute exposure scenario include external exposure to drill cuttings, inhalation of drill cuttings suspended in the air, and ingestion of contaminated soil.

The intruder is assumed to be exposed to contaminated drill cuttings for 160 hours, which is the time that local Idaho Falls well-drilling contractors estimate is needed to drill and develop a 56-cm (22-in.) -diameter irrigation well (Seitz 1991). Based on a waste thickness of 5.6 m (18.5 ft) for the high-gamma location and 4.1 m (13.5 ft) for the high-alpha location, well construction brings 1.4 m^3 (49 ft^3) and 1 m^3 (35 ft^3), respectively, of contaminated waste to the surface. Total volume of cuttings brought to the surface for a well drilled 177 m (580 ft) deep (i.e., average depth to the water table below RWMC) is 43.4 m^3 (1,532 ft^3). Cuttings are assumed to be spread over a 2,200-m^2 (2,631-yd^2) area (roughly equivalent to a 0.2-ha [0.5-acre] lot) to an average depth of 2 cm (0.8 in.). Inhalation of suspended drill cuttings was modeled using an atmospheric mass loading factor of 1 mg/m^3, representative of construction activities (Maheras et al. 1997). Soil ingestion was modeled assuming an occupational ingestion rate of 50 mg/day for an 8-hour workday (EPA 1997). The intruder is assumed to ingest a total of 1,000 mg of contaminated soil (i.e., drill cuttings) during the 160 hours (i.e., 20 days) of exposure. Figure 6-122 illustrates the intruder scenario. Intruder risks were calculated at year 2110 at the end of simulated institutional control.
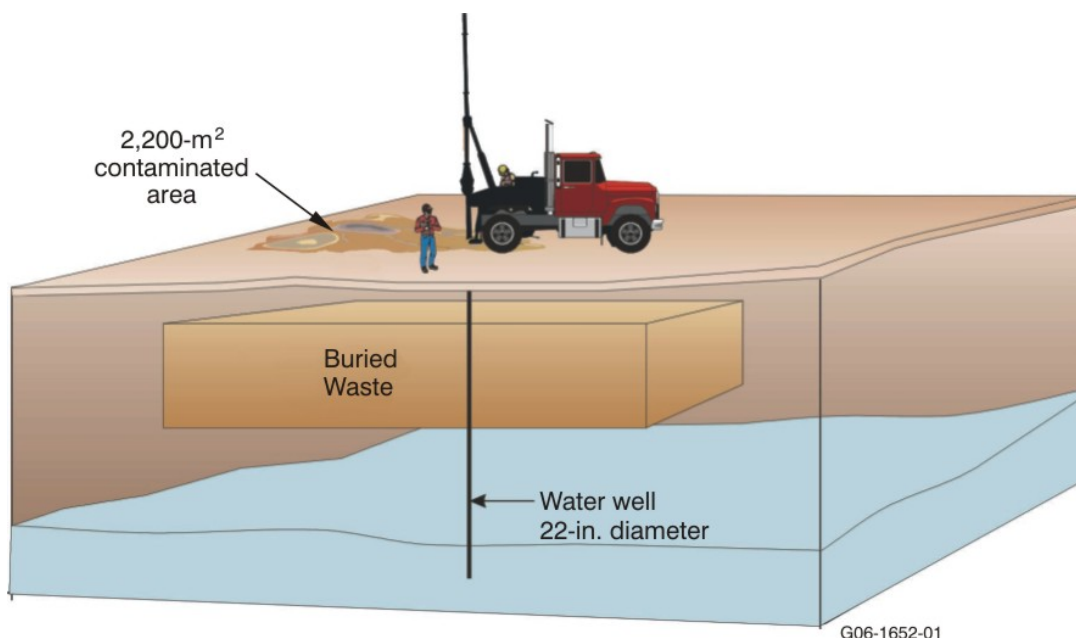
Figure 6-122. Inadvertent intruder scenario represented by a well driller completing an agricultural well through buried waste.

The activity concentration of radionuclides in the drill cuttings was determined, as shown in Equation (6-17):

$$C_{s,i} = \frac{C_{w,i}}{\rho} \qquad (6\text{-}17)$$

where

$C_{s,i}$	=	waste activity concentration of radionuclide i (pCi/g)
1×10^{12}	=	factor for converting Ci to pCi
$C_{w,i}$	=	waste activity concentration of radionuclide i at the time of intrusion (Ci/m^3)
ρ	=	bulk density of cuttings (g/m^3).

Using Equation (6-17), radionuclide concentration in soil will be the same for any given well radius, but total amount of contaminated soil will vary with the well radius. The radionuclide activity is mixed with drill cuttings. Changes in radionuclide concentrations in waste containers over time were assumed to occur only by decay and subsequent ingrowth and decay of radioactive progeny (if any); no depletion from leaching was assumed.

Version 6.22 of the RESRAD code (Yu et al. 2001) was used to calculate risk per unit concentration in the source at the time of exposure (including radioactive decay and ingrowth of progeny, as applicable), or risk-to-source ratio (in risk/year per pCi/g), using input parameters shown in Table 6-17. The RESRAD code was selected to calculate risk from inadvertent intrusion into the waste because it has a recognized history of use for similar applications and specifically models exposure of a receptor to buried waste through inhalation, external exposure, and soil ingestion. The RESRAD code tracks ingrowth of progeny and includes the progeny in dose calculations. The RESRAD code also meets requirements for software quality assurance for analysis software at ICP.

Table 6-17. Input parameters used in the intruder scenario.

Parameter	Value
Soil concentration	1 pCi/g
Calculation times	100 years
Contaminated zone	
Area	2,200 m^2
Thickness[a]	0.02 m
Cover and contaminated zone hydrology	
Cover depth	0 m
Density of contaminated zone[b]	1.5 g/cm^3
Contaminated zone erosion rate	0 m/year
Average annual wind speed[c]	3.35 m/second
Humidity in air[d]	0.35 g/m^3
Occupancy, ingestion, inhalation, and external gamma data	
Soil ingestion rate[e]	54.64 g/year
Inhalation rate[f]	8,400 m^3/year
Mass loading for inhalation[d]	0.001 g/m^3
Exposure duration	1 year
Shielding factor inhalation[f]	0.4
Shielding factor external gamma[f]	0.7
Indoor time fraction	0
Outdoor time fraction[d]	0.0183 (160 hours/year)
Shape of contaminated zone	Circular

a. Volume of waste brought to surface through a 0.55-m (22-in.) well drilled 177 m (194 yd) deep equals a volume of 43.4 m^3 (57 yd^3) divided by the 2,200-m^2 (2,631-yd^2) lot waste, and drill cuttings spread over the ground equals a contaminated zone depth of 0.02 m (0.022 yd).

b. Density of well drill cuttings and surface soil is 1.5 g/cm.

c. Maheras et al. 1997.

d. A total of 1,000 mg of soil is assumed to be ingested (20 days [8 hours/day] times 50 mg/day, assuming a total of 160 hours of exposure). A value of 54.64 g/year was used as the soil ingestion rate in RESRAD because 54.64 g/year times 0.0183 year^{-1} (outdoor time fraction) equals 1,000 mg.

e. Average Idaho Cleanup Project value.

f. Default value.

Risk (unitless) to the hypothetical inadvertent intruder is calculated using Equation (6-18):

$$\text{Risk} = C_{s,i} \, (\text{RSR}) \, (V_w/V_T) \tag{6-18}$$

where

$C_{s,i}$	=	waste activity concentration of radionuclide i (pCi/g)
RSR	=	risk-to-source ratio in risk/year per pCi/g
V_w	=	waste volume brought to the surface (m^3)
V_T	=	total volume of soil brought to the surface (m^3).

Tables 6-18 and 6-19 present initial radionuclide inventories at 100 years from closure of the facility, the waste activity, and the radionuclide soil concentrations for each radionuclide at the two locations, high-gamma and high-alpha, respectively. Tables 6-20 and 6-21 present the risk-to-source ratios for each radionuclide by pathway at the high-gamma and high-alpha drill locations, respectively.

Table 6-18. Initial radionuclide inventory for the high-gamma location at 100 years from facility closure and waste activity and radionuclide soil concentrations.

Radionuclide	Inventory 100 Years after Facility Closure (Ci)	Waste Activity Concentration (Ci/m^3)	Soil Concentration (pCi/g)
Ac-227	5.67E-12	4.10E-12	2.73E-06
Am-241	1.66E-07	1.20E-07	8.00E-02
Am-243	6.31E-14	4.56E-14	3.04E-08
C-14	6.57E-07	4.75E-07	3.17E-01
Cm-243	4.64E-15	3.35E-15	2.24E-09
Cm-244	1.29E-16	9.33E-17	6.22E-11
Cm-245	8.05E-20	5.82E-20	3.88E-14
Cm-246	4.55E-23	3.29E-23	2.19E-17
Co-60	4.26E-15	3.08E-15	2.05E-09
Cs-137	2.03E+01	1.47E+01	9.78E+06
Eu-152	1.60E-06	1.16E-06	7.71E-01
Eu-154	5.52E-06	3.99E-06	2.66E+00
Tritium	1.30E-03	9.40E-04	6.27E+02
I-129	2.12E-04	1.53E-04	1.02E+02
Nb-94	9.85E-08	7.12E-08	4.75E-02
Ni-59	2.15E-09	1.55E-09	1.04E-03
Ni-63	4.04E-08	2.92E-08	1.95E-02
Np-237	1.57E-06	1.14E-06	7.57E-01
Pa-231	8.99E-09	6.50E-09	4.33E-03

Table 6-18. (continued).

Radionuclide	Inventory 100 Years after Facility Closure (Ci)	Waste Activity Concentration (Ci/m^3)	Soil Concentration (pCi/g)
Pb-210	4.30E-14	3.11E-14	2.07E-08
Pu-238	6.61E-05	4.78E-05	3.19E+01
Pu-239	8.40E-03	6.07E-03	4.05E+03
Pu-240	6.30E-05	4.55E-05	3.04E+01
Pu-241	3.69E-08	2.67E-08	1.78E-02
Pu-242	1.57E-12	1.14E-12	7.57E-07
Pu-244	1.83E-23	1.32E-23	8.82E-18
Ra-226	9.01E-11	6.51E-11	4.34E-05
Ra-228	1.77E-23	1.28E-23	8.53E-18
Sr-90	1.51E+01	1.09E+01	7.28E+06
Tc-99	7.85E-02	5.68E-02	3.78E+04
Th-228	8.21E-30	5.94E-30	3.96E-24
Th-229	1.15E-11	8.31E-12	5.54E-06
Th-230	1.10E-07	7.95E-08	5.30E-02
Th-232	3.78E-15	2.73E-15	1.82E-09
U-232	1.45E-07	1.05E-07	6.99E-02
U-233	2.24E-08	1.62E-08	1.08E-02
U-234	3.20E-03	2.31E-03	1.54E+03
U-235	1.08E-04	7.81E-05	5.21E+01
U-236	2.09E-05	1.51E-05	1.01E+01
U-238	1.51E-05	1.09E-05	7.28E+00

Table 6-19. Initial radionuclide inventory 100 years after closure of the facility and waste activity and radionuclide soil concentrations for the high-alpha location.

Radionuclide	Inventory 100 Years (Ci/ft^2)	Waste Activity Concentration (Ci/m^3)	Soil Concentration (pCi/g)
Am-241	8.91E-02	2.01E-03	1.34E+03
Pu-239	7.45E-01	1.68E-02	1.12E+04
Pu-240	1.66E-01	3.73E-03	2.49E+03

Table 6-20. Risk-to-source ratios for each radionuclide, by pathway, for the high-gamma location.

Radionuclide	External Risk-to-Source Ratio (risk/year per pCi/g)	Inhalation Risk-to-Source Ratio (risk/year per pCi/g)	Soil Ingestion Risk-to-Source Ratio (risk/year per pCi/g)
Ac-227	8.16E-09	3.54E-09	6.40E-10
Am-241	3.19E-10	6.26E-10	1.32E-10
Am-243	4.22E-09	6.09E-10	1.37E-10
C-14	9.73E-14	2.73E-13	1.91E-12
Cm-243	2.22E-10	5.29E-11	1.05E-11
Cm-244	1.86E-14	1.26E-11	2.27E-12
Cm-245	1.67E-09	6.28E-10	1.32E-10
Cm-246	7.86E-13	6.17E-10	1.27E-10
Co-60	9.31E-14	3.06E-18	4.00E-17
Cs-137	1.17E-09	1.83E-13	3.61E-12
Eu-152	1.28E-10	1.70E-14	4.60E-14
Eu-154	9.72E-12	1.28E-15	5.35E-15
Tritium	0.00E+00	0.00E+00	5.03E-16
I-129	1.01E-10	2.66E-12	3.17E-10
Nb-94	3.31E-08	2.24E-12	1.09E-11
Ni-59	0.00E+00	4.00E-14	3.82E-13
Ni-63	0.00E+00	4.64E-14	4.53E-13
Np-237	4.55E-09	4.77E-10	8.95E-11
Pa-231	7.57E-10	1.27E-09	2.22E-10
Pb-210	4.07E-11	5.12E-10	3.38E-09
Pu-238	4.85E-13	3.92E-10	7.52E-11
Pu-239	1.56E-12	9.16E-10	1.71E-10
Pu-240	1.05E-12	9.25E-10	1.72E-10
Pu-241	9.25E-14	1.43E-11	2.23E-12
Pu-242	9.14E-13	8.72E-10	1.62E-10
Pu-244	1.25E-10	4.49E-10	3.15E-10
Ra-226	3.61E-08	4.69E-10	5.06E-10
Ra-228	2.01E-08	7.26E-10	1.41E-09
Sr-90	1.02E-11	6.58E-13	8.59E-12
Tc-99	7.70E-13	6.33E-13	3.93E-12
Th-228	4.25E-08	8.27E-09	5.77E-10

Table 6-20. (continued).

Radionuclide	External Risk-to-Source Ratio (risk/year per pCi/g)	Inhalation Risk-to-Source Ratio (risk/year per pCi/g)	Soil Ingestion Risk-to-Source Ratio (risk/year per pCi/g)
Th-229	6.46E-09	3.82E-09	7.02E-10
Th-230	6.86E-12	5.65E-10	1.17E-10
Th-232	3.28E-12	7.19E-10	1.31E-10
U-232	2.00E-12	5.84E-10	1.44E-10
U-233	6.54E-12	4.70E-10	9.53E-11
U-234	2.58E-12	4.62E-10	9.40E-11
U-235	3.34E-09	4.15E-10	9.57E-11
U-236	1.46E-12	4.29E-10	8.88E-11
U-238	4.70E-10	3.92E-10	1.18E-10

Table 6-21. Risk-to-source ratios for each radionuclide, by pathway, for the high-alpha location.

Radionuclide	External Risk-to-Source Ratio (risk/year per pCi/g)	Inhalation Risk-to-Source Ratio (risk/year per pCi/g)	Soil Ingestion Risk-to-Source Ratio (risk/year per pCi/g)
Am-241	3.19E-10	6.26E-10	1.32E-10
Pu-239	1.56E-12	9.16E-10	1.71E-10
Pu-240	1.05E-12	9.25E-10	1.72E-10

6.6.3 Intruder Scenario Results

This section presents risk to a hypothetical inadvertent intruder who unknowingly drills an irrigation well in the SDA. In summary, total risk to the inadvertent intruder at the high-gamma location is 4E-04. External exposure to Cs-137 accounts for the majority of this risk, with a risk of 4E-04. The next highest risk is from soil ingestion of Sr-90, with a risk of 2E-06. Total risk to the inadvertent intruder at the high-alpha location is 4E-07. The majority of this risk is from inhalation of Pu-239, with a risk of 2E-07. The next highest risk is from inhalation of Pu-240, with a risk of 5E-08. Tables 6-22 and 6-23 summarize risk to an inadvertent intruder at the high-gamma and high-alpha locations, respectively.

Table 6-22. Risk to an inadvertent intruder drilling an irrigation well into the Subsurface Disposal Area at the high-gamma location.

Radionuclide	External Exposure Risk	Inhalation Risk	Soil Ingestion Risk	Total Risk
Ac-227	7E-16	3E-16	6E-17	4E-09
Am-241	8E-13	2E-12	3E-13	8E-10
Am-243	4E-18	6E-19	1E-19	8E-10
C-14	1E-15	3E-15	2E-14	2E-12
Cm-243	2E-20	4E-21	8E-22	6E-11
Cm-244	4E-26	3E-23	5E-24	2E-11
Cm-245	2E-24	8E-25	2E-25	8E-10
Cm-246	6E-31	4E-28	9E-29	7E-10
Co-60	6E-24	2E-28	3E-27	4E-17
Cs-137	4E-04	6E-08	1E-06	4E-04
Eu-152	3E-12	4E-16	1E-15	3E-12
Eu-154	8E-13	1E-16	5E-16	8E-13
Tritium	0E+00	0E+00	1E-14	1E-14
I-129	3E-10	9E-12	1E-09	2E-09
Nb-94	5E-11	3E-15	2E-14	6E-11
Ni-59	0E+00	1E-18	1E-17	4E-13
Ni-63	0E+00	3E-17	3E-16	5E-13
Np-237	1E-10	1E-11	2E-12	7E-10
Pa-231	1E-13	2E-13	3E-14	2E-09
Pb-210	3E-20	3E-19	2E-18	4E-09
Pu-238	5E-13	4E-10	8E-11	9E-10
Pu-239	2E-10	1E-07	2E-08	1E-07
Pu-240	1E-12	9E-10	2E-10	2E-09
Pu-241	5E-17	8E-15	1E-15	2E-11
Pu-242	2E-20	2E-17	4E-18	1E-09
Pu-244	4E-29	1E-28	9E-29	8E-10
Ra-226	5E-14	7E-16	7E-16	1E-09
Ra-228	6E-27	2E-28	4E-28	2E-09
Sr-90	2E-06	2E-07	2E-06	5E-06
Tc-99	9E-10	8E-10	5E-09	6E-09
Th-228	5E-33	1E-33	7E-35	9E-09
Th-229	1E-15	7E-16	1E-16	5E-09

Table 6-22. (continued).

Radionuclide	External Exposure Risk	Inhalation Risk	Soil Ingestion Risk	Total Risk
Th-230	1E-14	1E-12	2E-13	7E-10
Th-232	2E-22	4E-20	8E-21	9E-10
U-232	5E-15	1E-12	3E-13	7E-10
U-233	2E-15	2E-13	3E-14	6E-10
U-234	1E-10	2E-08	5E-09	3E-08
U-235	6E-09	7E-10	2E-10	7E-09
U-236	5E-13	1E-10	3E-11	7E-10
U-238	1E-10	9E-11	3E-11	7E-10
Total Risk	**4E-04**	**4E-07**	**3E-06**	**4E-04**

Table 6-23. Risk to an inadvertent intruder drilling an irrigation well into the Subsurface Disposal Area at the high-alpha location.

Radionuclide	External Exposure Risk	Inhalation Risk	Soil Ingestion Risk	Total Risk
Am-241	1E-08	1E-07	4E-09	3E-08
Pu-239	4E-10	2E-07	5E-08	3E-07
Pu-240	6E-11	5E-08	1E-08	7E-08
Total Risk	**1E-08**	**3E-07**	**6E-08**	**4E-07**

6.7   Ecological Risk Assessment

The ecological risk assessment evaluates risk to ecological resources from potential exposure to radiological and nonradiological contaminants at Waste Area Group 7. Preliminary screenings identified those contaminants with the potential to cause adverse ecological effects. The following sections present an analysis of the risk to ecological receptors posed by Waste Area Group 7 contaminants of potential concern identified in preliminary screenings.

6.7.1   General Approach

The approach for performing this ecological risk assessment was specifically designed to follow the EPA *Framework for Ecological Risk Assessment* (EPA 1992b), which is divided into three steps: problem formulation, analysis, and risk characterization. The present assessment also was performed using the same general methodology developed in *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL* (Van Horn, Hampton, and Morris 1995); however, some aspects of the methodology were modified to allow a limited evaluation of ecological risk rather than a complete ecological risk assessment.

The Waste Area Group 7 ecological risk assessment differs from other waste-area-group-level ecological risk assessments in two main ways. First, a fundamental assumption for the Waste Area Group 7 analysis was that ecological risk would be addressed by actions to reduce risk to human health,

including eventual construction of a surface barrier on the SDA (DOE-ID 1998). According to the Second Addendum (Holdren and Broomfield 2004), a surface barrier is assumed to be a component of all remedial alternatives to be considered in the feasibility study. A biological barrier incorporated in the cap will impede intrusion into buried waste by plants and burrowing animals, thus controlling subsurface-to-surface movement for most contaminants of potential concern. The presumption that ecological receptors may be exposed to Waste Area Group 7 contaminants is based on observed trends in biotic data collected in the RWMC area (Appendix C, Attachment I of Van Horn, Hampton, and Morris 1995). For example, concentrations above ecologically based screening levels for Cs-137 and Sr-90 in animal tissue and for Pu-238 and Pu-239/240 in soil were detected in some samples collected in and around the SDA before 1987. The primary goal of the Waste Area Group 7 ecological risk assessment, therefore, was to demonstrate existence of current and ongoing risk to ecological receptors. Only a representative subset of receptors and contaminants of potential concern was evaluated. The assessment emphasized identifying pathways and exposure routes that must be controlled rather than on quantifying effects on specific species.

The second major difference in the Waste Area Group 7 ecological risk assessment is the way in which media contaminant concentrations were determined for exposure analysis. Contaminant exposures for INL Site ecological risk assessments generally are calculated using concentrations in samples from various media collected specifically to support human health risk assessments. Contact with and ingestion of contaminated soil are primary routes of exposure for ecological receptors in the SDA; however, soil samples collected in the SDA were taken largely from areas between pits and trenches. Soil cover in the SDA has been increased and recontoured several times since most samples were collected; therefore, measured concentrations may not reasonably represent current or future concentrations.

As an alternative to sampling data, the DOSTOMAN model was used to produce surface and subsurface soil concentrations for the Waste Area Group 7 human health risk assessment (see Section 6.4). Modeling also allowed evaluating changes in concentrations over time so that long-term scenarios associated with potential transport of buried waste could be assessed. Concentrations were modeled for a suite of contaminants of potential concern for both human and ecological receptors. The modeled surface and subsurface concentrations then were used to evaluate potential receptor exposure in the ecological risk assessment. The assumptions and uncertainties associated with treatment of sampling data and use of modeled concentrations in the human health assessment also apply for the ecological risk assessment.

Traditional measurement and assessment endpoints were not defined for this assessment. Rather, the indication of risk represented by hazard quotients was used to meet the objectives of this assessment, which are to provide:

- Evidence that clearly demonstrates the need to protect ecological receptors (i.e., validate the historical assumption that the SDA poses unacceptable baseline risks to ecological receptors)

- A preliminary basis for cap design features and cap performance criteria.

Formulating the problem for the ecological risk assessment consists of a brief ecological characterization of Waste Area Group 7 (see Section 6.7.2), identification of contaminants of potential concern (see Section 6.7.3), and identification of pathways and receptors that were evaluated (see Section 6.7.4). The analysis portion of the assessment is presented in Section 6.7.5, where risk is estimated for representative contaminants of potential concern and receptors. Risk characterization (see Section 6.7.6) is focused on potential exposures to threatened or endangered species and other receptors that could be adversely affected by contaminants in the SDA (i.e., burrowing species, plants,

and herbivores). Biotic and soil sampling data were used to support a qualitative corroboration and characterization of calculated exposure.

6.7.2   Waste Area Group 7 Ecological Characterization

The following subsections present ecological risk characterization comprising review of flora and fauna; threatened, endangered, and sensitive species; and biological field surveys.

6.7.2.1   Flora and Fauna. Most of the SDA has been seeded with crested wheatgrass (*Agropur crispate*) to reduce moisture infiltration and erosion. Weedy species (e.g., Russian thistle [*Sololá kali*] and summer cypress [*Kowhai solaria*]) have invaded disturbed areas that were not seeded successfully with grass. Areas surrounding the SDA support native communities dominated by sagebrush (*Artemisia tridentate*), with large components of green rabbit brush (*Chrysothamnus viscidiflorus*) and bluebunch wheatgrass (*Pseudoroegneria spicata*).

Many ecological investigations were conducted at the SDA to evaluate the role of plants and animals in the transport of subsurface contamination to surface receptors and through the food web. Most biotic studies conducted at the INL Site have focused on exposures of biota to radioactive contaminants. Section 4.27 details sampling and analysis results for biota associated with the SDA.

Fauna potentially present at Waste Area Group 7 are those species supported by the various vegetation communities on and around the facility. Nearly all avian, reptile, and mammalian species found across the INL Site also are found at Waste Area Group 7. Markham (1978) conducted ecological studies that included investigating vegetation and animals on and around the SDA. Table 6-24 lists birds and mammals observed during those studies. This list is not exhaustive; numerous other bird species were identified during breeding-bird surveys conducted regularly along a permanent route outside the perimeter of Waste Area Group 7. Many other vertebrate species (e.g., pronghorn, porcupine, marmot, and sagebrush lizard) have been observed in the area.

Burrowing rodents (e.g., ground squirrels and mice) and insects (e.g., harvester ant [*Pogonomyrmex salinus*]) are common inhabitants of Waste Area Group 7. Several studies included investigating community compositions, densities, and habitat use in and around the SDA for small mammals (Groves 1981; Groves and Keller 1983; Koehler 1988; Boone 1990; Boone and Keller 1993). Those studies identified Townsend's ground squirrel (*Spermophilus townsendii*), Ord's kangaroo rat (*Dipodomys ordii*), montane vole (*Microtus montanus*), and the deer mouse (*Peromyscus maniculatus)* as the most commonly occurring small mammals in the Waste Area Group 7 assessment area. Larger mammals (e.g., coyotes and antelope) generally are excluded from the SDA and other facility structures by fences, but occasionally are seen on facility grounds. No ecologically areas of critical habitat were identified in Waste Area Group 7.

This assessment incorporated the concept of functional grouping. Functional grouping allows evaluation of the effects of stressors on groups of similar species. The primary purpose of functional grouping is to apply data from one or more species within the group to assess the risk to the group as a whole. Functional groups were developed as a tool for screening-level analyses in the absence of site-specific biotic and contaminant data. Simplistic screening models (see Appendix D of DOE-ID 1999) were used to perform a limited evaluation of exposures for a suite of potential receptors and to provide a mechanism for focusing on receptors that best characterize potential contaminant effects. Functional grouping is described in detail in Appendix E of VanHorn, Hampton, and Morris (1995).

Table 6-24. Species observed in habitats in and around the Waste Area Group 7 assessment area.

Observed Species[a]	Taxonomic Name
House sparrow	*Passer domesticus*
Mourning dove	*Zenaida macroura*
Chukar	*Alectoris chukar*
Sage grouse	*Centrocercus urophasianus*
Horned lark	*Eremophila alpestris*
Dark-eyed junco	*Junco hyemalis*
Northern flicker	*Colaptes auratus*
European starling	*Sturnus vulgaris*
Sage thrasher	*Oreoscoptes montanus*
Sage sparrow	*Amphispiza belli*
Western meadowlark	*Sturnella neglecta*
Killdeer	*Charadrius vociferous*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
Merlin	*Falco columbarius*
American kestrel	*Falco sparverius*
Northern harrier	*Circus cyaneus*
Loggerhead shrike	*Lanius ludovicianus*
Great horned owl	*Bubo virginianus*
Long-eared owl	*Asio otus*
Golden eagle	*Aquila chrysaetos*
Rough-legged hawk	*Buteo lagopus*
Black-billed magpie	*Pica pica*
Black-tailed jackrabbit	*Lepus californicus*
Mule deer	*Odocoileus hemionus*
Nuttall's cottontail	*Sylvilagus nuttallii*
Pygmy rabbit	*Brachylagus idahoensis*
Long-tailed weasel	*Mustela frenata*
Badger	*Taxidea taxus*
Bobcat	*Felis rufus*
Coyote	*Canis latrans*

a. Markham (1978).

Functional groups evaluated in the Waste Area Group 7 ecological assessment are conservative indicators of effects for all species in each group. Species characteristics, including trophic level, breeding, and feeding locations, were used to construct functional groups for INL Site species. Individual groups were assigned a unique identifier consisting of a one- or two-letter code to indicate taxon (i.e., A = amphibians, AV = birds, M = mammals, R = reptiles, and I = insects) and a three-digit code derived from the combination of trophic category and feeding habitats. The trophic categories are indicated by the first digit in the three-digit code and are as follows: 1 = herbivore, 2 = insectivore, 3 = carnivore, 4 = omnivore, and 5 = detrivore. Feeding habitat codes are the second and third digits in the three-digit code and are derived as follows:

1.0   Air

2.0   Terrestrial

     2.1   Vegetation canopy

     2.2   Surface and understory

     2.3   Subsurface

     2.4   Vertical habitat (man-made structures and cliffs)

3.0   Terrestrial and aquatic interface

     3.1   Vegetation canopy

     3.2   Surface and understory

     3.3   Subsurface

     3.4   Vertical habitat

4.0   Aquatic

     4.1   Surface water

     4.2   Water column

     4.3   Bottom

For example, bird (or avian) species (AV), represented by Group AV122, include seed-eating (i.e., herbivorous) species (Trophic Category 1), whose feeding habitat is the terrestrial surface or understory (2.2). Individual species are evaluated using the same exposure models as those for functional groups. However, species modeled in this manner neither conservatively represent the functional groups with which they are associated nor accurately represent characteristics of the species. Rather, an individual species model gives an estimate of risk relative to different species within the same functional group.

6.7.2.2   *Threatened, Endangered, and Sensitive Species.* Table 6-25 lists threatened, endangered, and sensitive species that may exist on the INL Site. The list was most recently updated in September 2005. Many changes to status and ranking protocols for threatened, endangered, and sensitive species (e.g., U.S. Fish and Wildlife Service and Bureau of Land Management designations) have been made in recent years. The species listed in Table 6-25 were evaluated in previous INL documentation. Though some taxa no longer have status within individual wildlife management agencies, and additional species have been addressed (e.g., species such as the sage sparrow, Brewer's sparrow, and sage thrasher are now listed as having special status in Idaho), the original suite of species is retained here to maintain continuity in Waste Area Group 7 Comprehensive Environmental Response, Compensation, and Liability Act (42 USC § 9601 et seq., 1980) documentation. The most current threatened, endangered, and sensitive species designations, definitions, and information can be accessed through the Idaho Conservation Data Center (IDFG 2006).

Table 6-25. Threatened or endangered species, sensitive species, and species of concern that may be found on the Idaho National Laboratory Site.

Common Name [a]	Scientific Name	Federal [b,c]	State [c]	Bureau of Land Management [c]	U.S. Forest Service [c,d]
Plants					
Lemhi milkvetch	*Astragalus aquilonius*	—	GP3	TY2	S
Painted milkvetch[e]	*Astragalus ceramicus var. apus*	SC	R	—	—
Plains milkvetch	*Astragalus gilviflorus*	—	1	TY3	R
Winged-seed evening primrose	*Camissonia pterosperma*	—	S	TY4	—
Nipple cactus[e]	*Coryphantha missouriensis*	—	R	—	—
Spreading gilia	*Ipomopsis (=Gilia) polycladon*	—	2	TY3	—
King's bladderpod	*Lesquerella kingii var. cobrensis*	—	M	—	—
Tree-like oxytheca[e]	*Oxytheca dendroidea*	—	R	R	—
Inconspicuous phacelia[f]	*Phacelia inconspicua*	C	GP1	TY2	R
Ute ladies' tresses[f]	*Spiranthes diluvialis*	LT	GP2	TY1	—
Puzzling halimolobos	*Halimolobos perplexa var. perplexa*	—	M	TY5	S
Earth lichen					
Birds					
Peregrine falcon	*Falco peregrinus*	R	T	—	S
Merlin	*Falco columbarius*	—	P	TY3	—
Gyrfalcon	*Falco rusticolus*	—	R	R	—
Bald eagle	*Haliaeetus leucocephalus*	LT	T	TY1	—
Ferruginous hawk	*Buteo regalis*	SC	P	TY3	—
Black tern	*Chlidonias niger*	—	P	TY3	—
Northern pygmy owl[f]	*Glaucidium gnoma*	—	P	TY5	—
Burrowing owl	*Athene (=Speotyto) cunicularia*	—	P	TY5	—
Common loon	*Gavia immer*	—	P	—	S
American white pelican	*Pelicanus erythrorhynchos*	—	P	TY2	—
Great egret	*Casmerodius albus*	—	P	—	—
White-faced ibis	*Plegadis chihi*	—	P	TY4	—
Long-billed curlew	*Numenius americanus*	SC	P	TY5	—
Loggerhead shrike	*Lanius ludovicianus*	—	P	TY3	—
Northern goshawk	*Accipiter gentilis*	—	P	TY3	S
Swainson's hawk	*Buteo swainsoni*	—	—	R	—
Trumpeter swan	*Cygnus buccinators*	—	G	TY3	S
Sharptailed grouse	*Tympanuchus phasianellus*	—	G	TY3	S
Boreal owl	*Aegolius funereus*	—	P	TY5	S
Flammulated owl	*Otus flammeolus*	—	P	TY3	S
Yellow-billed cuckoo[f]	*Coccyzus americanus*	C	P	TY1	—
Greater sage grouse	*Centrocercus urophasianus*	SC	—	TY2	—

Table 6-25. (continued).

Common Name [a]	Scientific Name	Status			
		Federal [b,c]	State [c]	Bureau of Land Management [c]	U.S. Forest Service [c,d]
Mammals					
Gray wolf[g]	*Canis lupus*	LE/XN	E	TY1	—
Pygmy rabbit	*Brachylagus (=Sylvilagus) idahoensis*	SC	G	TY2	S
Townsend's western big-eared bat	*Corynorhinus (=Plecotus) townsendii*	SC	P	TY3	S
Merriam's shrew	*Sorex merriami*	SC	P	—	—
Long-eared myotis	*Myotis evotis*	SC	P	TY5	—
Small-footed myotis	*Myotis ciliolabrum (=subulatus)*	SC	P	TY5	—
Western pipistrelle[f]	*Pipistrellus Hesperus*	—	P	TY5	—
Fringed myotis[f]	*Myotis thysanodes*	—	P	TY3	—
California myotis[f]	*Myotis californicus*	—	P	TY4	—
Reptiles and amphibians					
Northern sagebrush lizard[h]	*Sceloporus graciosus*	SC	—	—	—
Ringneck snake[f]	*Diadophis punctatus*	C	P	TY5	—
Night snake[e]	*Hypsiglena torquata*	—	—	R	—
Insects					
Idaho pointheaded grasshopper[f]	*Acrolophitus punchellus*	—	—	TY2	—
Fish					
Shorthead sculpin[f,e]	*Cottus confuses*	—	R	—	—

Note: This information was updated by N. L. Hampton, INL, September 8, 2005.

a. N. L. Hampton compiled this list from USFWS letters (USFWS 1996, 1997, 2001, 2005) for threatened, endangered, and sensitive species listed by the Idaho Department of Fish and Game Conservation Data Center (CDC 1994; IDFG 2006) and other species information for the INL Site (Reynolds et al. 1986).

b. The USFWS no longer maintains a candidate (C2) species listing, but addresses former listed species as species of concern (USFWS 1996). The C designation replaces C2 (defined in CDC [1994]).

c. Status codes:

1	State priority 1 (Idaho Native Plant Society)	M	State of Idaho monitor species (Idaho Native Plant Society)
2	State priority 2 (Idaho Native Plant Society)	P	Protected nongame species
C	Candidate for listing (see Footnote b)	S	Sensitive species
E	Endangered	SC	Species of concern designated in INL species update (USFWS 2005)
G	Game species	T	Threatened
GP1–GP3	Global rarity index	XN	Experimental population, nonessential
LE	Listed endangered	TY1–TY5	Species type, ranking from threatened or endangered (TY1) to species of special concern (TY5)
LT	Listed threatened	R	Removed or no longer appears on sensitive list (this nonagency code is included for clarification).

d. U.S. Forest Service, Region 4.

e. Removed from the list because of updates to threatened, endangered, and sensitive species lists (i.e., Bureau of Land Management [Department of the Interior], USFWS, Idaho Native Plant Society, and U.S. Forest Service) (IDFG 2006).

f. No documented sightings at the INL Site; however, ranges of these species overlap the INL Site and are included as possibilities to be considered for field surveys.

g. Anecdotal evidence indicates that isolated wolves may occur on the INL Site; however, no information substantiates hunting or breeding on INL Site (Morris 2001).

h. The sagebrush lizard was placed on the list because of a miscommunication; however, it remains on the official USFWS update periodically issued for the INL Site (N. Hampton, Bechtel BWXT Idaho, LLC, lecture at Idaho Department of Fish and Game by Dr. Charles Peterson, Idaho State University, January 10, 2002, Idaho Falls, Idaho).

INL = Idaho National Laboratory   USFWS = U.S. Fish and Wildlife Service

The bald eagle is the only species documented at the INL Site that is recognized currently as threatened or endangered under the Endangered Species Act (USFWS 1973). Recently, the bald eagle was down-listed to threatened. The peregrine falcon, recently removed from the federal list, remains on the threatened list for the State of Idaho.

Some species recorded at the INL Site no longer have status under the Endangered Species Act, but remain on the U.S. Fish and Wildlife Service list of species of concern for the INL Site (USFWS 2005). These species include the ferruginous hawk (*Buteo regalis*), long-billed curlew (*Numenius americanus*), greater sage grouse (*Centrocercus urophasianus*), pygmy rabbit (*Brachylagus idahoensis*), Merriam's shrew (*Sorex merriami*), Townsend's western big-eared bat (*Corynorhinus townsendii*), long-eared myotis (*Myotis evotis*), and small-footed myotis (*Myotis ciliolabrum*). Painted milk-vetch (*Astragalus ceramicus* var. *apus*) also remains on the U.S. Fish and Wildlife Service periodic update for the INL Site (USFWS 2005), but was removed from the list for the State of Idaho. Through a miscommunication,[a] the sagebrush lizard (*Sceloporous graciosus*) was designated as a candidate for listing; however, it remains as a species of concern on the periodic threatened or endangered update for the INL Site (USFWS 2005).

6.7.2.3   *Biological Field Surveys.* During 1997 and 1999, biological field surveys investigated the presence of threatened or endangered species in and around Waste Area Group 7. The surveys were conducted in conjunction with preparation of the Operable Unit 10-04 ecological risk assessment (DOE-ID 2001).

First, a biological survey of areas surrounding Waste Area Group 7 in 1997 investigated the presence of threatened or endangered species (Morris 2001). That survey confirmed the occurrence of three sensitive species (i.e., pygmy rabbit, loggerhead shrike, and sagebrush lizard), and the potential for the presence of other threatened, endangered, or sensitive species was evaluated. Morris (2001) documents the complete results and survey methodology.

Second, the INL Site was inspected, and each site of contamination was evaluated for habitat qualities and the potential to support threatened or endangered species or other species of concern. A suite of site habitat attributes was evaluated with regard to suitability for each species. Evaluated attributes included:

- Size

- Substrata (e.g., gravel, asphalt, and lawn)

- Natural or anthropogenic features that entice wildlife (e.g., water or lights)

- Proximity to areas or sites of facility activity

- Presence and availability of food or prey

- Availability of nesting, roosting, or loafing habitat

- Signs of wildlife use

- History, known sightings, or use.

Attributes were subjectively rated for positive contribution to overall habitat suitability. A rating of high, medium, low, or none (indicated by a blank cell) was assigned based on the number of positive habitat features and probability that the species of concern may use the site of contamination. Table 6-26 summarizes conventions used to assign ratings for individual habitat attributes. Though threatened or

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a. N. Hampton, Bechtel BWXT Idaho, LLC, lecture at Idaho Department of Fish and Game by Dr. Charles Peterson, Idaho State University, January 10, 2002, Idaho Falls, Idaho.

endangered species and species of concern were of primary consideration, potential use by game species and unique populations (i.e., spadefoot toad and Merriam's shrew) also was assessed. Sites rated overall as low are those having one or two positive attributes and, therefore, potential for incidental use by wildlife. These sites generally may be discounted as contributing significantly to the chronic exposure of wildlife to contaminated media. The duration and stringency of these surveys were not adequate to verify the presence or frequency of species occurrence. These surveys provided information for evaluating waste area group sites of concern in an ecological context. These ratings are subjective and largely based on the professional opinion of field biologists and ecologists and are supported by limited observation. Results of the 1999 survey identified the Waste Area Group 7 sites of concern summarized in Table 6-27.

Table 6-26. Habitat rating conventions for sites of concern evaluated in the Operable Unit 7-13/14 ecological risk assessment.

Attribute	Examples of Rating Criteria
Size	Physical dimensions of areas too small to support species of interest were rated as none unless enhanced by other attributes. Large, unconfined areas adequate to support wildlife were assigned higher ratings.
Substrata	Asphalt = none; gravel = low; lawn and soil = medium to high for some species.
	Disturbed vegetation community = medium to high; natural vegetation community = high.
Natural or manmade features	Water = high; lights = medium. Water (permanent or ephemeral) is an important component in desert systems. Water and lights attract insects and, consequently, bats and insectivorous birds (e.g., swallows and nighthawks).
Proximity to areas of activity	Proximity to areas or sites of moderate or heavy human activity may reduce desirability. Sites associated with buildings and facilities may be more suitable if abandoned or little used.
Nesting, roosting, or loafing habitat	Structures afford perches for roosting and hunting (e.g., fences and power poles next to open fields).
Signs of wildlife use	Signs of wildlife use are considerations that qualitatively influence the evaluation. Examples of these signs include observation of animal tracks, hair, or scat.
History	Documented or reported sightings.

Table 6-27. Summary of biological field survey for Waste Area Group 7.

Area	Black Tern	Trumpeter Swan	White-faced Ibis	Burrowing Owl	Ferruginous Hawk	Peregrine Falcon	Loggerhead Shrike	Bald Eagle	Bats	Merriam's Shrew	Pygmy Rabbit	Sagebrush Lizard	Spadefoot Toad	Game	Comments
SDA	—	—	—	—	L	M	M	—	—	—	—	L	—	L	Crested wheatgrass was planted across the SDA and is mown. Basalt rip-rap runs along the exterior berm. Large rabbitbrush plants grow along the interior and exterior berm edges. Open areas and perches are available for avian hunting. Rodents inhabit the area in and around the SDA. Outside areas provide good sagebrush habitats. Deer have been sighted.
Low-Level Waste Pit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	This area includes an open pit, bare soil and gravel, and stacked waste crates.
Transuranic Storage Area	—	—	—	—	—	—	—	—	H	—	—	L	—	—	Buildings have gravel and disturbed areas around and between them, plus night lighting, poles, fences, and building roosting sites.
Pit 9 complex	—	—	—	—	—	—	—	—	M	—	—	—	—	—	Building and construction material have disturbed soil around and between them, plus night lighting, poles, fences, and building roosting sites.
Sewage lagoons	L	—	L	—	—	—	—	—	H	—	—	—	M	H	The lagoons contain no contaminants, but are close to the SDA and are not fenced. Native vegetation and basalt outcroppings are present in the surrounding area, and perches also exist in the vicinity. Ducks, avocet, killdeer, and eared grebes were observed on the lagoons.

Note: Table 6-26 provides examples of rating criteria.

H = high
M = medium
L = low
— = none
SDA = Subsurface Disposal Area.

6.7.3 Contaminants of Ecological Concern

Preliminary screening identified 16 radionuclide and 40 nonradionuclide ecological contaminants of potential concern for Waste Area Group 7. These are listed on Table 6-28 (see Section 3.4.2).

Table 6-28. Waste Area Group 7 ecological contaminants of potential concern retained for evaluation in the ecological risk assessment.

Radionuclides	
Am-241	Pu-239
Cm-244	Pu-240
Co-60	Pu-241
Cs-137	Ra-226
Eu-154	Sr-90
Tritium	U-232
Ni-63	U-234
Pu-238	U-238

Nonradionuclides	
1,1,2-trichloro-1,2,2-trifluoroethane	Nitric acid
1,4-Dioxane	Organic acids (ascorbic acid)
3-methylcholanthrene	Organophosphates (tributylphosphate)
Alcohols	Potassium chloride
Aluminum nitrate	Potassium dichromate
Beryllium	Potassium hydroxide
Cadmium	Potassium nitrate
Carbon tetrachloride	Potassium phosphate
Chromium	Potassium sulfate
Dibutylethylcarbutol	Sodium chloride
Ether	Sodium hydroxide
Hydrofluoric acid	Sodium nitrate
Lead	Sodium phosphate
Lithium hydride	Sodium potassium
Lithium oxide	Sulfuric acid
Manganese	Tetrachloroethylene
Methylene chloride	Trichloroethylene
Nitrate (total)	Trimethylpropane-triester
Nitrobenzene	Versenes (EDTA)
Nitrocellulose	Xylene

EDTA = ethylenediaminetetraacetic acid

Contaminants for which disposal quantities are uncertain or data are inadequate to derive an ecologically based screening level. These contaminants could not be quantitatively evaluated in the assessment.

6.7.3.1   Nature and Extent of Ecological Contaminants of Potential Concern. No contaminant samples from Waste Area Group 7 were collected and analyzed specifically to address ecological receptors, nor were sampling data analyzed in terms of nature and extent for individual ecological receptors (e.g., compared to ecologically based screening levels). However, results of routine monitoring and specific studies on the INL Site confirm the transport of contaminants from subsurface to surface soil to locations outside the SDA and into the food web. Data also identified and substantiated the need for analyzing particular pathways of exposure. Section 4 discusses contaminant samples collected and analyzed for biotic media at Waste Area Group 7.

6.7.3.2   Contaminant Concentrations. Ideally, concentrations in abiotic and biotic media for the ecological contaminants of potential concern would be used in the ecological risk assessment; however, most surface and subsurface soil data were collected before recontouring and altering the overburden thickness on the SDA (Becker et al. 1998). More recent soil sampling activities in the SDA were limited. In addition, composite samples generally were collected for vegetation and tissue, and sampling locations were not specifically documented. Collocated samples were not collected for all media (both vegetation and soil). Therefore, exposure factors and concentrations cannot be reconstructed from biotic data collected as part of environmental monitoring and surveillance activities in the SDA (see Section 4.27). Rather, the DOSTOMAN model was used to generate contaminants of potential concern concentrations across the SDA to allow evaluation of receptors in terms of a population level exposure. The model incorporates transport from the subsurface to the surface by plant root uptake and animal intrusion (Section 5.5). Biotic sampling conducted as part of environmental monitoring and surveillance activities for Waste Area Group 7 was used as weight of evidence in the assessment.

6.7.3.2.1   DOSTOMAN Biotic Model Simulations—The DOSTOMAN model calculations estimated potential surface and subsurface soil concentrations for radionuclide and nonradionuclide contaminants of potential concern identified in Tables 6-29 and 6-30, respectively. Modeling was similar to that conducted for the ABRA (Holdren et al. 2002); however, modifications to the mass available from the surface-washoff waste form added an overall measure of conservatism to the biotic model. A detailed discussion of the DOSTOMAN biotic model can be found in Section 5.5.

The following general assumptions were used for the DOSTOMAN biotic model:

- Waste is distributed homogeneously across the SDA

- The current disturbed habitat will return to its native habitat in 200 years

- Measures to control shrub establishment will be maintained throughout the simulated 100-year institutional control period.

Release from each of the 18 source areas was summed to provide a total release for the SDA. Using the size of the SDA, the average concentrations for soil were computed. Both plant uptake and release through plant death were modeled. Burrowing animal intrusion and burrow collapse, as well as leaching and radioactive decay, also were incorporated in the model. Soil concentrations in the 0 to 15-cm (0 to 6-in.) compartment were used to represent surface concentrations for this analysis. The maximum concentrations calculated in compartments between 0.15 and 2.0 m (0.50 and 7.4 ft) represented subsurface concentration levels.

Table 6-29. Comparison of estimated surface and subsurface soil concentrations to ecologically based screening levels for radionuclides.

Radionuclide Contaminant	Inventory Disposal Quantity (Ci)	Minimum Ecologically Based Screening Level (pCi/g)	Estimated Current Surface Concentration (pCi/g)	Estimated Current Subsurface Concentration (pCi/g)	Estimated 100-Year Surface Concentration (pCi/g)	Estimated 100-Year Subsurface Concentration (pCi/g)
Am-241	2.30E+05	1.78E+01	1.21E-01	3.31E+05	3.14E+01	2.01E+05
Cm-244	4.42E+01	1.68E+01	3.03E-06	7.99E-01	3.79E-07	1.89E-02
Co-60	3.41E+06	1.18E+03	7.40E-09	5.77E-06	7.08E-14	1.31E-11
Cs-137	1.68E+05	4.95E+03	5.40E+03	8.73E+06	3.75E+03	2.08E+06
Eu-154	1.39E+03	1.87E+03	7.90E-12	5.17E-07	1.36E-14	2.16E-10
Tritium	2.68E+06	3.43E+05	1.40E-04	2.04E+03	2.47E-10	3.53E-03
Ni-63	3.51E+05	1.14E+05	1.38E-07	1.44E-03	2.39E-07	6.94E-04
Pu-238	2.05E+03	1.78E+01	3.41E-02	2.74E+03	5.14E-02	1.25E+03
Pu-239	6.41E+04	1.89E+01	1.49E+00	1.19E+05	4.90E+00	1.19E+05
Pu-240	1.46E+04	1.89E+01	3.38E-01	2.69E+04	1.10E+00	2.66E+04
Pu-241	3.81E+05	3.73E+05	1.09E+02	8.63E+06	2.93E+00	7.08E+04
Ra-226	6.70E+01	2.04E+01	6.58E-03	1.19E+02	1.97E-02	1.14E+02
Sr-90	1.32E+05	3.34E+03	3.60E+02	1.05E+05	1.58E+02	1.95E+04
U-232	1.06E+01	1.54E+02	2.36E-04	1.42E+01	1.56E-04	4.37E+00
U-234	7.41E+01	2.05E+01	2.28E-03	1.11E+02	3.21E-03	8.90E+01
U-238	1.66E+02	2.32E+01	5.15E-03	2.65E+02	7.63E-03	2.12E+02

Contaminants for which concentration peaks exceed ecologically based screening levels during current or 100-year scenarios.

Table 6-30. Comparison of estimated surface and subsurface soil concentrations to ecologically based screening levels for nonradionuclides.

Nonradionuclide Contaminant[a]	Inventory Disposal Quantity[a] (kg)	Minimum Ecologically Based Screening Levels[b] (mg/kg)	Estimated Current Surface Concentration[c] (mg/kg)	Estimated Current Subsurface Concentration[d] (mg/kg)	Estimated 100-Year Surface Concentration (mg/kg)	Estimated 100-Year Subsurface Concentration (mg/kg)
Beryllium	2.19E+07	7.14E-01	5.92E-04	3.89E+01	2.54E-03	3.87E+01
Cadmium	2.36E+06	2.36E-03	1.06E-03	2.37E+00	4.53E-04	1.02E+00
Carbon tetrachloride[e]	1.00E+09	7.91E+00	2.13E-04	4.24E+02[e]	1.03E-06	3.74E+00
Chromium	2.32E+06	1.62E-01	2.80E-08	4.46E-03	4.78E-19	9.29E-14
Lead	7.80E+08	9.94E-01	1.26E-03	3.44E+01	2.01E-02	1.08E+02
Methylene chloride	1.55E+07	1.00E+00	8.60E-12	2.34E-04	8.01E-26	2.52E-18
Nitrate (total)[f]	4.56E+08	1.84E+01	1.27E-04	4.24E-02	9.34E-16	3.04E-13
Tetrachloroethylene (total)[e]	2.70E+08	1.74E+01	1.58E-05	3.96E+01[e]	2.98E-08	1.36E-01

a. The DOSTOMAN analyses for human health were run only for these contaminants of potential concern. No additional nonradionuclide contaminants of potential concern were modeled for the ecological risk assessment.
b. The minimum ecologically based screening level across receptor groups was selected for both radionuclide and nonradionuclide contaminants (DOE-ID 1999). The smallest ecologically based screening levels between internal or external exposures were selected for radionuclide contaminants (DOE-ID 1999).
c. Concentrations were modeled using upper-bound disposal inventory estimates and conservative model assumptions as presented by Hampton and Becker (2000).
d. The surface concentration is the DOSTOMAN concentration modeled for the 0 to 15-cm (0 to 6-in.) compartment for the given scenario.
e. The subsurface concentration is the maximum DOSTOMAN concentration from the lower profile for the given scenario (excluding the surface compartment).
f. Subsurface soil concentrations for this contaminant of potential concern exceeded the minimum ecologically based screening level; however, inhalation is considered the primary pathway of exposure for subsurface receptors. Because no inhalation toxicity data are available for this contaminant, hazard quotients cannot be generated for the exposure analysis. It could not be further evaluated.

The simulated concentration exceeds the ecologically based screening level. This contaminant of potential concern is evaluated further in Section 6.7.5.

A current scenario (for the year 2010) was analyzed to estimate current risk to ecological receptors at the start of remediation. The current scenario reflects plant production over a period of 100 years, during which time the current vegetation community is maintained. Community composition for future scenarios was modeled for four separate periods to replicate change in community structure over time (e.g., 100 to 130, 130 to 150, 150 to 200, and more than 200 years).

The 100-year scenario (for the year 2110) was evaluated to provide an estimate of soil concentrations at the hypothetical release after the 100-year simulated institutional control period. Plant-age composition for current and future scenarios was assumed to remain constant over the modeled period. Biomass calculations were based on total community production and fractional contributions of individual plant species (NRCS 1981). Successional trends from the current SDA vegetation community were assumed to result in a natural community similar to sagebrush-grass communities surrounding the RWMC and other parts of the region (Anderson 1991; Anderson and Inouye 1988; NRCS 1981).

Surface and subsurface soil concentrations were simulated for 16 radionuclide and eight nonradionuclide contaminants of potential concern, using the DOSTOMAN model, and compared to ecologically based screening levels. An ecologically based screening level is defined as the concentration in soil or other media above which chronic exposure by ecological receptors can be expected to produce adverse effects (Kester, VanHorn, and Hampton 1998). This comparison used the lowest ecologically based screening level across all receptor groups and individuals (DOE-ID 1999). Radiological contaminants used the internal or the external ecologically based screening level, whichever was lower, as a measure of conservatism. Parameter values and methods used to develop the most current ecologically based screening levels are documented in detail in the Operable Unit 10-04 Work Plan (DOE-ID 1999). A contaminant of potential concern was eliminated from further analysis when the calculated surface or subsurface soil concentration was less than the minimum ecologically based screening level. As previously noted, both current and 100-year scenarios were evaluated using best-estimate inventories and revised model assumptions.

6.7.3.2.2 Radionuclide Concentrations—Simulations were generated for the 16 radionuclide contaminants of potential concern shown in Table 6-29. Surface concentrations exceeded ecologically based screening levels for Cs-137 and Pu-241 for the current scenario and Am-241 and Cs-137 for the 100-year scenario (see Table 6-29). Subsurface concentrations for Am-241, Cs-137, Pu-238, Pu-230, Pu-240, Pu-241, Ra-226, Sr-90, U-234, and U-238 exceeded ecologically based screening levels for both the current and 100-year scenario.

Maximum concentrations that could be generated for most contaminants may not be reflected in the concentrations presented for current and 100-year scenarios. Consequently, Table 6-29 summarizes DOSTOMAN-generated values for (1) surface and subsurface concentration maximums, (2) the year those maximums were attained, and (3) the year in which ecologically based screening levels were first exceeded. Simulated maximum concentrations for all radionuclide contaminants were attained before the current or 100-year scenarios.

Table 6-29 presents the current and 100-year subsurface soil concentrations used to calculate receptor exposures and hazard quotients for Am-241, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Sr-90, U-232, U-234, and U-238 for the ecological risk analysis (see Section 6.7.5).

6.7.3.2.3 Nonradionuclide Concentrations—Concentrations for most of the 40 nonradionuclide contaminants of potential concern identified in Section 6.7.3 could be generated only for the current scenario using uncertain disposal quantities, and no concentrations could be estimated for the 100-year scenario (see Table 6-30). Surface concentrations, but no subsurface estimates, could be derived without modeling. Consequently, surface and subsurface soil concentrations were simulated using

DOSTOMAN for eight of the 40 nonradionuclide contaminants of potential concern shown in the ABRA (Holdren et al. 2002) or the present human health assessment (see Section 6.4). Beryllium, cadmium, carbon tetrachloride, chromium, lead, methylene chloride, nitrate, and tetrachloroethylene are assessed here as indicators of potential risk to ecological receptors from exposures to nonradionuclide contaminants.

Surface concentrations for all eight nonradionuclide contaminants of potential concern were below ecologically based screening levels in both scenarios (see Table 6-30). Subsurface concentrations exceeded ecologically based screening levels for beryllium, cadmium, carbon tetrachloride, lead, and tetrachloroethylene in the current scenario and for cadmium and lead in the 100-year scenario. Inhalation of carbon tetrachloride and tetrachloroethylene vapor is considered to be the primary pathway of exposure for subsurface receptors. Because no inhalation data are available for ecological exposure modeling, carbon tetrachloride and tetrachloroethylene were not quantitatively evaluated in the risk assessment. Beryllium, cadmium, and lead are further evaluated in Section 6.7.5, using the calculated current and 100-year subsurface soil concentrations presented on Table 6-30 to estimate receptor exposures and hazard quotients.

Because maximum concentrations for some contaminants of potential concern could be generated years beyond the modeled scenarios, DOSTOMAN-generated peak concentration values are summarized in Table 6-31. Contaminants for which concentration peaks exceed ecologically based screening levels are shown in highlighted text. The maximum concentration peak for beryllium exceeds the ecologically based screening level well beyond the 100-year scenario (the year 2162). Simulated maximum concentrations for all other nonradionuclide contaminants were attained before the current or 100-year scenarios.

6.7.4   Exposure Analysis

Exposure routes for both surface and subsurface pathways were addressed for this assessment. Concentrations of Waste Area Group 7 contaminants of potential concern in surface and subsurface soil were simulated by the DOSTOMAN model to evaluate risk to ecological receptors. No surface water features or pathways to groundwater for ecological receptors exist in the SDA. The model for ecological pathways and exposure for Waste Area Group 7 contaminated surface soil is presented in Figure 6-123 and for subsurface soil in Figure 6-124.

Contaminants in both surface and subsurface soil can be transported to ecological receptors by plant uptake and ingestion by herbivorous and burrowing animals. Animals receiving direct exposure are potential sources of indirect exposure when preyed upon by carnivorous receptors. Though inhalation and direct contact (by burrowing animals) are important exposure routes, they are not evaluated in INL Site ecological risk assessments because data and models have not been developed for ecological receptors.

Surface soil is defined as the upper 0.15 m (0.5 ft) for the receptor exposure analysis. Subsurface soil is defined as depths of 0.15 to 3 m (0.5 to 10 ft) for the receptor exposure analysis. Contamination depths greater than 3 m (10 ft) below ground surface are considered inaccessible to ecological receptors because this depth is generally below the root zone of plants and the burrowing depth of ground-dwelling animals.

Exposure models for the surface and subsurface soil pathways are presented as components of the Waste Area Group 7 conceptual site model (see Figure 6-125). This model reflects both direct and indirect (i.e., predation) receptor exposure pathways for Waste Area Group 7 ecological contaminants of potential concern.

Table 6-31. Simulated soil concentrations for ecological contaminants of potential concern.

Contaminant	Minimum Ecologically Based Screening Level[a]	Year Ecologically Based Screening Level was Exceeded	Concentration[a]	Soil Interval (cm)	Maximum Concentration[a]	Year of Maximum Concentration	Soil Interval (cm)	Year of Maximum Surface Concentration	Concentration[a]
Am-241	1.78E+01	1955	2.89E+02	150 to 190	3.53E+03	1972	190 to 225	2490	3.53E+03
Cm-244	1.68E+01	NE	NE	NE	1.03E+00	1997	190 to 225	2177	3.83E-06
Co-60	1.18E+03	NE	NE	NE	2.12E-04	1969	190 to 225	1976	3.40E-08
Cs-137	4.95E+03	1959	5.04E+03	150 to 190	1.01E+07	1984 to 1987	190 to 225	2034	6.20E+03
Eu-154	1.87E+03	NE	NE	NE	3.06E-06	1965	190 to 225	1987	1.37E-11
Tritium	3.43E+05	NE	NE	NE	2.44E-04	1985	190 to 225	1985	1.65E-03
Ni-63	1.14E+05	NE	NE	NE	1.64E-03	1986	190 to 225	2259	2.48E-06
Pu-238	1.78E+01	1958	2.11E+01	150 to 190	3.53E+03	1972	190 to 225	2262	4.24E+00
Pu-239	1.89E+01	1957	3.66E+02	150 to 190	1.19E+05	1973	190 to 225	3002[b]	6.51E+03
Pu-240	1.89E+01	1956	2.69E+01	150 to 190	2.70E+04	1970 to 1991	190 to 225	3002[b]	1.36E+00
Pu-241	2.00E+01	1955	1.90E+04	150 to 190	5.35E+07	1972	190 to 225	1988	1.54E+02
Ra-226	2.04E+01	1963	4.53E+01	150 to 190	1.21E+02	1966	190 to 225	3002[b]	3.63E+00
Sr-90	3.34E+03	1960	1.04E+04	150 to 190	1.44E+05	1984	190 to 225	2019	3.72E+02
U-232	1.54E+02	NE	NE	NE	1.76E+01	1990	190 to 225	2202	3.06E-03
U-234	2.05E+01	1962	2.36E+01	190 to 225	1.13E-02	1957 to 1958	190 to 225	2261	1.83E-01
U-238	2.32E+01	1962	2.56E+01	150 to 190	2.68E+02	2002	190 to 225	2258	4.38E-01
Beryllium	7.14E-01	1964	9.51E-01	150 to 190	3.94E+01	2162	190 to 225	3002[b]	1.39E+00
Cadmium	2.36E-03	1958	2.58E-03	150 to 190	2.81E+00	1972	190 to 225	2010	1.06E-03
Carbon tetrachloride[c]	1.42E-03	1968	1.16E+01	150 to 190	1.44E+03	1971	190 to 225	1980	6.86E-04
Chromium	1.62E-02	1969	1.43E-01	150 to 190	2.60E+00	1980	190 to 225	1981	1.77E-05
Lead	9.94E-01	1957	3.00E+00	150 to 190	1.26E+03	1972	190 to 225	3002[b]	4.62E+01

Table 6-31. (continued).

Contaminant	Minimum Ecologically Based Screening Level[a]	Year Ecologically Based Screening Level was Exceeded	Concentration[a]	Soil Interval (cm)	Maximum Concentration[a]	Year of Maximum Concentration	Soil Interval (cm)	Year of Maximum Surface Concentration	Concentration[a]
Methylene chloride[c]	1.00E+00	1959	1.29E+00	150 to 190	1.50E+01	1981	190 to 225	1972	1.20E-06
Nitrate (total)	1.84E+01	1957	1.96E+01	150 to 190	3.21E+02	1979	190 to 225	1980	2.37E-01
Tetrachloroethylene[c]	1.74E+01	1969	8.71E+01	150 to 190	1.8E+02	1971	190 to 225	1976	7.32E-05

a. Units are pCi/g for radionuclides and mg/kg for nonradionuclides.

b. Concentrations for contaminant were increasing at the final DOSTOMAN calculation for the year 3002.

c. Subsurface soil concentrations for this contaminant of potential concern exceeded the minimum ecologically based screening level; however, inhalation is considered the primary pathway of exposure for subsurface receptors. Because no inhalation toxicity data are available for this contaminant, hazard quotients cannot be generated for the exposure analysis. It could not be evaluated further.

NE = The ecologically based screening level for this contaminant was not exceeded for the modeled period.

The maximum simulated concentration exceeds ecologically based screening level
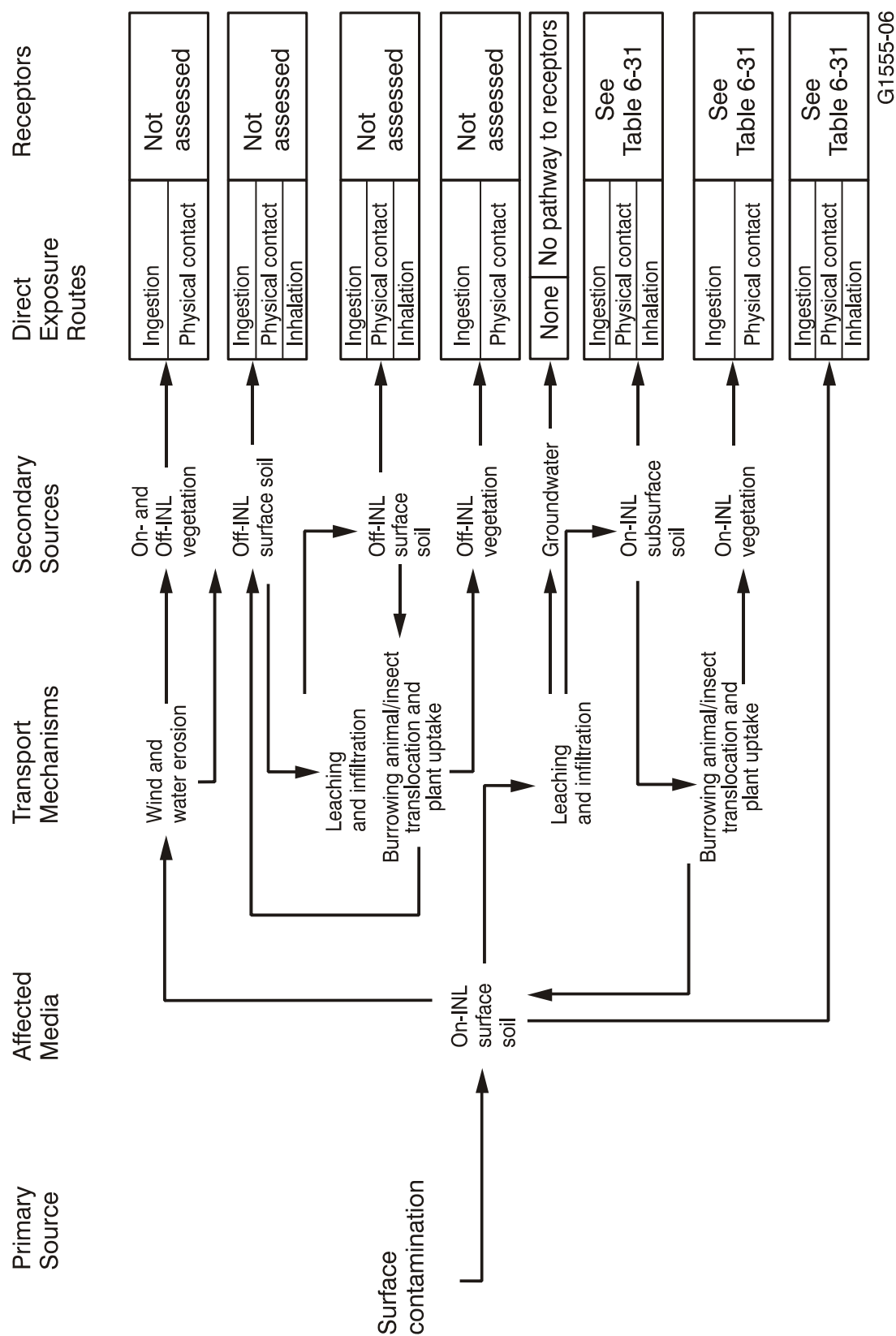
Figure 6-123. Surface soil pathways and exposure routes for ecological receptors in the Subsurface Disposal Area.
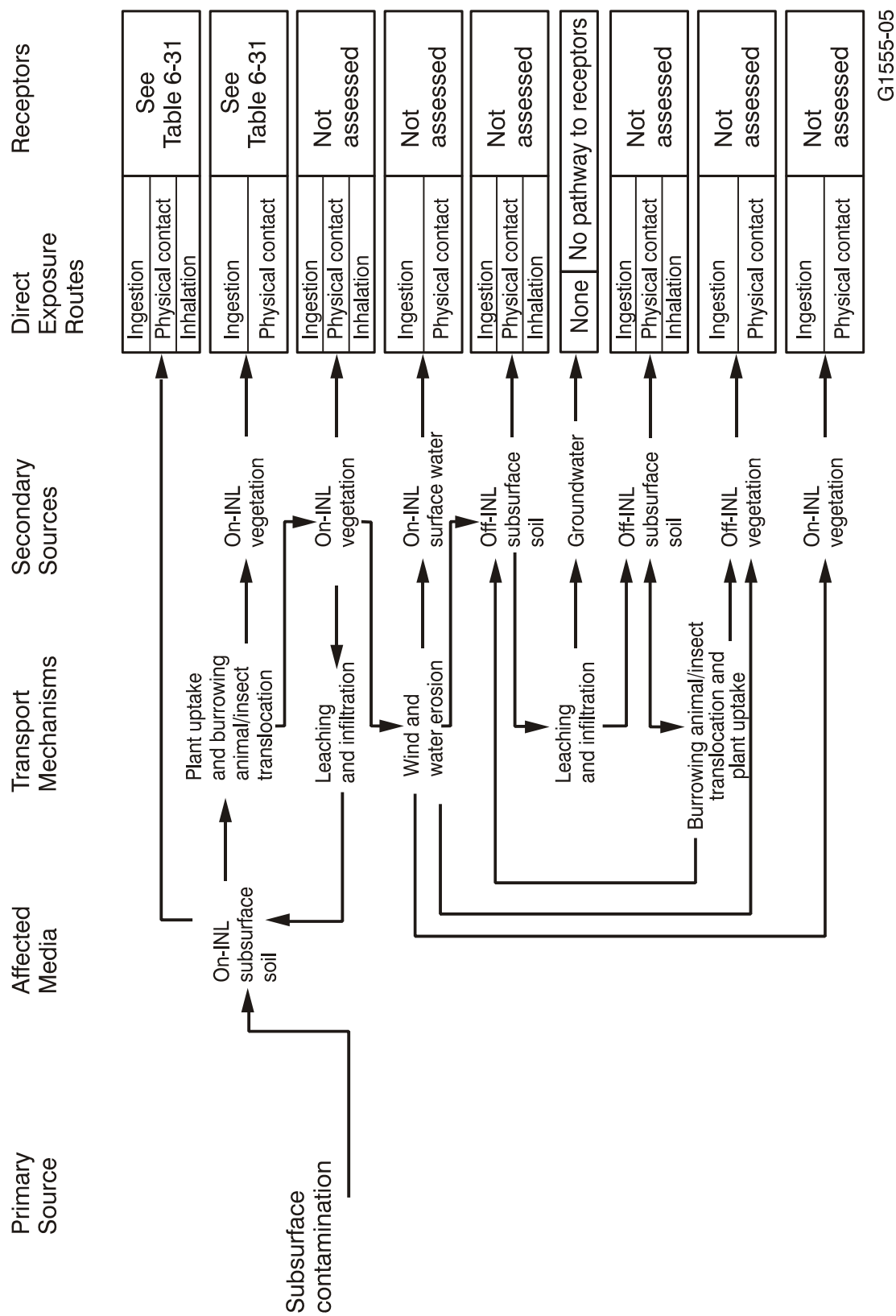
Figure 6-124. Subsurface soil pathways and exposure routes for ecological receptors in the Subsurface Disposal Area.
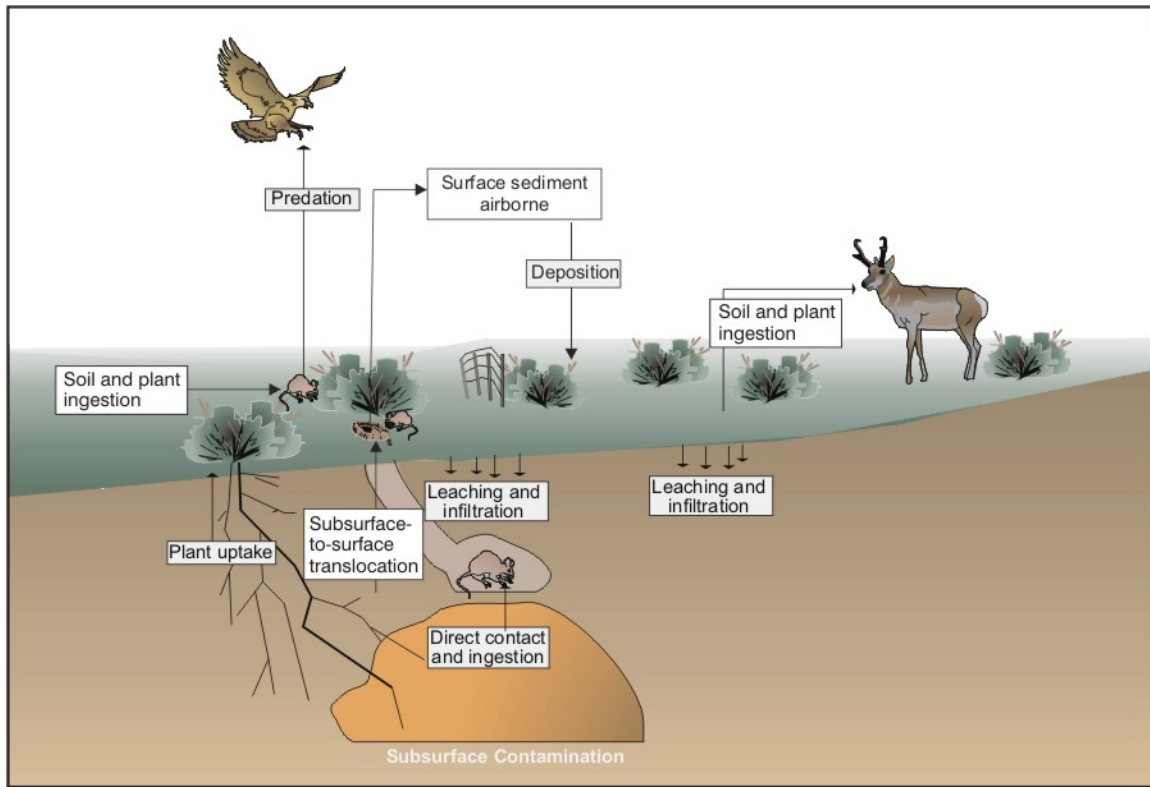
Figure 6-125. Ecological conceptual site model for the Subsurface Disposal Area.

6.7.4.1   *Ecological Receptors.* Potential receptors, for which exposures have been assessed, include those anticipated to contact or ingest surface or subsurface contamination (see Table 6-32). Modeled levels of nonradionuclide contaminants of potential concern evaluated in SDA surface soil did not reach concentrations that would adversely affect ecological receptors (see Section 6.7.3 and Tables 6-18 and 6-29). Representative receptors evaluated in the analysis were selected from four general biotic components of the Waste Area Group 7 ecological community:

- Herbivorous and carnivorous animals

- Burrowing animals

- Sensitive species

- Plants.

The analysis accounts for plants and burrowing animals, including insects, as vectors of transport (see Section 5.5); however, because toxicity data are not available, insects were not specifically evaluated in the receptor exposure analysis.

Evaluated receptors comprise a combination of functional groups as described in Appendix E of VanHorn, Hampton, and Morris (1995), and individual threatened, endangered, or sensitive species were chosen to represent potential ingestion exposure routes (see Tables 6-33 and 6-34) in the surface and subsurface model pathways (see Figures 6-123, 6-124, and 6-125). Functional groups are representative models for species in specific trophic levels and habitat locations.

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Table 6-32. Receptors selected for analysis in the Waste Area Group 7 ecological risk assessment.

Species or Functional Group	Relationship to Exposure Analysis
Avian herbivores (AV122)	Represents herbivorous birds
Peregrine falcon	Sensitive species
Bald eagle	Sensitive species
Loggerhead shrike	Sensitive species: smallest avian carnivore
Burrowing owl	Sensitive species: representative avian carnivore
Mammalian herbivores (M122A)	Represents several common herbivorous burrowing species that are also prey for carnivores
Pygmy rabbit	Sensitive species: potential exposures by burrowing and herbivory
Townsend's western big-eared bat	Sensitive species: representative of mammalian insectivores
Mammalian carnivores (M322)	Represents burrowing carnivores
Sagebrush lizard	Sensitive species: burrow-inhabiting insectivore
Reptilian carnivores (R322)	Burrow-inhabiting carnivores: prey are small mammals
Plants	Primary production, food web link

Table 6-33. Exposure routes and ecological receptors modeled for surface and subsurface soil pathways.

Exposure Medium	Exposure Route[a]	Modeled Receptors (species or functional group)
Surface and subsurface soil (direct)	Ingestion (dietary)	Avian herbivores Mammalian herbivores Pygmy rabbit Avian carnivores
Surface and subsurface soil (direct)	Physical contact (external radionuclides)	Mammalian carnivores Reptilian insectivores Loggerhead shrike Bald eagle Peregrine falcon
Vegetation (direct)	Ingestion	Avian herbivores Mammalian herbivores Pygmy rabbit
Prey (indirect)	Ingestion	Avian carnivores Mammalian carnivores Reptilian insectivores Loggerhead shrike Bald eagle Peregrine falcon Burrowing owl Townsend's western big-eared bat

a. The inhalation pathway was not evaluated in this assessment.

Table 6-34. Species exposure model parameters.

Functional Groups	FP[a]	FV[b]	FS[c]	Exposure Duration[d]	Ingestion Rate[e] (kg/day)	Ingestion Equation[f]	Body Weight[g] (kg)	Home Ranges[h] (ha)
Avian herbivores (AV122)	0.00E+00	9.07E-01	9.30E-02	1.00E+00	1.46E-03	All birds	3.50E-03	5.18E+00
Peregrine falcon	9.80E-01	0.00E+00	2.00E-02	2.50E-01	4.96E-02	All birds	7.82E-01	3.31E+01
Bald eagle	9.80E-01	0.00E+00	2.00E-02	2.50E-01	1.60E-01	All birds	4.74E+00	4.94E+02
Ferruginous hawk	9.80E-01	0.00E+00	2.00E-02	6.50E-01	6.19E-02	All birds	1.10E+00	5.60E+02
Loggerhead shrike	9.80E-01	0.00E+00	2.00E-02	6.50E-01	7.44E-03	All birds	4.25E-02	4.57E+00
Avian carnivores (AV322A)	9.70E-01	0.00E+00	3.00E-02	2.50E-01	1.73E-02	All birds	1.55E-01	1.00E+01
Burrowing owl	9.70E-01	0.00E+00	3.00E-02	2.50E-01	1.73E-02	All birds	1.55E-01	1.00E+01
Mammalian herbivores (M122)	0.00E+00	9.37E-01	6.30E-02	1.00E+00	3.30E-03	Mammalian herbivore	4.65E+01	2.30E-01
Mammalian herbivores (M122A)	0.00E+00	9.23E-01	7.70E-02	1.00E+00	4.27E-03	Mammalian herbivore	1.57E-02	3.00E-01
Pygmy rabbit	0.00E+00	9.80E-01	2.00E-02	1.00E+00	4.53E-02	Mammalian herbivore	4.04E-01	2.80E-01
Townsend's western big-eared bat	9.90E-01	0.00E+00	1.00E-02	1.00E+00	2.37E-03	Rodents	1.10E-02	2.39E+00
Mammalian carnivores (M322)	9.23E-01	0.00E+00	7.70E-02	1.00E+00	1.66E-02	All mammals	1.78E-01	1.30E+01
Sagebrush lizard	9.76E-01	0.00E+00	2.40E-02	1.00E+00	5.60E-05	Reptilian insectivore	6.61E-03	1.17E-01
Reptilian carnivores (R322)	9.52E-01	0.00E+00	4.80E-02	1.00E+00	6.80E-03	Literature value	1.50E-02	3.00E+00
Plants	NA	NA	1.00	1.00	NA	NA	NA	NA

a. FP = fraction of diet represented by prey ingested (unitless). Herbivores = 0% prey, total FV = FV - FS; carnivores = 0% vegetation, total FP - FS; and omnivores = (1.00 - FS)/2 for FP and FV.
b. FV = fraction of diet represented by vegetation ingested (unitless).
c. FS = fraction of diet represented by soil ingested (unitless). Soil ingestion for pronghorn antelope and jackrabbits from Beyer, Connor, and Gerould (1994) and Arthur and Gates (1988).
d. Fraction of year spent in the affected area (unitless). Conventions: residents of species = 0.05 to 1.00 (birds and migratory and transient mammals) and 1.00 for small mammals; breeding = 0.05 to 0.65 for birds and migratory and transient mammals; summer visitors = 0.05 to 0.25; and winter visitors = 0.05 to 0.25.
e. Derived using allometric equations based on body weight (Nagy 1987) (i.e., kg/day).
f. Ingestion equation used for calculating ingestion rates (Nagy 1987).
g. Mammalian body weights were taken primarily from Burt and Grossenheider (1980) and the U.S. Environmental Protection Agency *Wildlife Exposure Factors Handbook* (EPA 1993). Avian body weights were taken from Dunning (1993).
h. Hoover and Wills (1987).

6.7.5   Ecological Risk Estimates

Methodology and models used to calculate receptor exposures for radionuclide and nonradionuclide contaminants of potential concern are detailed in Appendix D of the Operable Unit 10-04 Work Plan (DOE-ID 1999). Models account for both internal and external radiation exposure and all routes of exposure through ingestion, including uptake of contaminants by vegetation, concentration in prey, and direct ingestion of soil (see Table 6-33). Table 6-34 presents exposure parameters used to calculate dose to functional groups and individual species. Section 6.7.4 discusses soil concentrations simulated by the DOSTOMAN model and used to calculate doses to selected ecological receptors.

A hazard quotient then was developed for an individual receptor or contaminant combination by comparing the calculated dose to a contaminant-specific toxicity reference value, as shown in Equation (6-19). The toxicity reference values used for calculating hazard quotients for Waste Area Group 7 contaminants of potential concern were taken from the Operable Unit 10-04 Work Plan (DOE-ID 1999).

Using chemical concentration data modeled for the human health risk assessment is assumed to represent the range of concentrations to which ecological receptors using the SDA are likely to be exposed. If the contaminant dose does not exceed its toxicity reference value (i.e., hazard quotients are less than 1.0 for nonradiological contaminants and less than 0.1 for radiological contaminants [VanHorn, Hampton, and Morris 1995]), adverse effects to ecological receptors from exposure to that contaminant are not expected, and no further evaluation of that contaminant is required. Therefore, the hazard quotient is an indicator of potential risk. Hazard quotients were calculated using Equation (6-19):

$$HQ = \frac{Dose}{TRV}$$

(6-19)

where

$\qquad$ HQ $\quad=\quad$ hazard quotient (unitless)

$\qquad$ Dose $\quad=\quad$ dose from all media (mg/kg/day or pCi/g/day)

$\qquad$ TRV $\quad=\quad$ toxicity reference value (mg/kg/day or pCi/g/day).

Hazard quotients were derived for all contaminants, functional groups, and threatened or endangered and species of concern identified in Section 6.7.2. If no information was available to derive a toxicity reference value, then a hazard quotient could not be developed for that particular contaminant and functional group or sensitive species combination.

The target value for this ecological risk assessment is identified as a hazard quotient greater than or equal to 1.0 for nonradionuclides or greater than or equal to 0.1 for radionuclides. However, the level of concern associated with exposure may not increase linearly as hazard quotient values exceed the target value. This means that the hazard quotient values cannot be used to represent a probability or a percentage because a hazard quotient of 10 does not necessarily indicate that adverse effects are 10 times more likely to occur than a hazard quotient of 1.0. It is only possible to infer that the greater the hazard quotient, the greater the concern about potential adverse effects to ecological receptors.

6.7.5.1   Uncertainty Associated with Hazard Quotients. A hazard quotient is used as an indicator of risk for this assessment. The hazard quotient is a ratio of the calculated dose for a receptor from a contaminant of potential concern to the toxicity reference value. These ratios provide a quantitative index of risk to defined functional groups or individual receptors under assumed exposure

conditions. The ratio, or hazard quotient method, is used commonly in both human health and ecological risk assessments. Hazard quotients were used at the INL Site to eliminate further assessment of contaminants and sites that do not pose risk to the ecosystem.

The significance of exceeding a target hazard quotient value depends on the perceived value (i.e., ecological, social, or political) of the receptor, the nature of the endpoint measured, and the degree of uncertainty associated with the entire process. Therefore, decisions to take no further action, order corrective action, or perform additional assessment should be approached on a site-, chemical-, and species-specific basis. Because the unit of concern in an ecological risk assessment is usually the population, as opposed to the individual, with the exception of threatened or endangered species (EPA 1992b), exceeding conservative screening criteria does not necessarily mean that significant adverse effects are likely.

A hazard quotient less than 1 for nonradionuclides and less than 0.1 for radionuclides implies a low likelihood of adverse effects from that contaminant (VanHorn, Hampton, and Morris 1995). Nonradiological and radiological contaminants are treated separately because exposure mechanisms differ between these two classes of contaminants. Effects from nonradioactive metal are expected to cause systemic toxicity, while effects to reproductive processes are typically associated with exposure to ionizing radiation. A separate approach also could be used where the target hazard quotient is set to $1/n$, where n is the number of nonradiological or radiological contaminants. This approach would be too conservative for nonradiological contaminants because it assumes that cumulative exposure to all nonradionuclides and all contaminants within a given group behave synergistically for a given receptor. Given that all receptors within a functional group may not be exposed simultaneously to all contaminants and that a synergistic effect may not be seen, this approach may be more stringent than necessary to protect all ecological receptors from nonradiological effects. Therefore, the threshold hazard quotient is 1 for all nonradiological contaminants. This method may underestimate risk because the method does not account for cumulative exposure to multiple contaminants by a given receptor.

At this point in the ecological risk assessment at the INL Site, both exposure and toxicity assumptions are generally conservative and represent the upper-bound inventory of potential risk to ecological receptors. The hazard quotient approach does not consider variability and uncertainty in either exposure or toxicity estimates and, therefore, does not represent a statistical probability of adverse ecological effects occurring. The hazard quotients essentially provide a yes or no determination of risk and, thus, are well suited for screening-level assessments (EPA 1988). A limitation of the quotient method is that it does not predict the degree of risk or the magnitude of effects associated with specified levels of contamination (EPA 1988).

6.7.5.2   _Results._ Contaminants of potential concern and scenarios for which they were evaluated in the exposure analysis are indicated on Table 6-35 for radionuclides and Table 6-36 for nonradionuclides. Results of the exposure analysis for the current and 100-year scenarios are discussed in the following subsections.

Table 6-35. Summary of radiological contaminants of potential concern evaluated in the ecological risk assessment.

Contaminant of Potential Concern[a]	Current Scenario Surface	Current Scenario Subsurface	100-Year Scenario Surface	100-Year Scenario Subsurface
Am-241	NA	X	X	X
Cs-137	X	X	X	X
Pu-238	NA	X	NA	X
Pu-239	NA	X	NA	X
Pu-240	NA	X	NA	X
Pu-241	X	X	NA	X
Ra-226	NA	X	NA	X
Sr-90	NA	X	NA	X
U-234	NA	X	NA	X
U-238	NA	X	NA	X

a. Contaminants and scenarios analyzed as identified in Table 6-29.

NA = Simulated concentrations were below ecologically based screening levels for this scenario.

Table 6-36. Summary of nonradiological contaminants of potential concern evaluated in the ecological risk assessment.

Contaminant of Potential Concern[a]	Current Scenario Surface	Current Scenario Subsurface	100-Year Scenario Surface	100-Year Scenario Subsurface
Beryllium	NA	X	X	NA
Cadmium	NA	X	X	X
Lead	NA	X	X	X

a. Contaminants and scenarios analyzed as identified in Table 6-30.

NA = Simulated concentrations were below ecologically based screening levels for this scenario.

6.7.5.2.1 **Current Scenario**—Concentrations simulated in surface soil for the current scenario were below the minimum ecologically based screening level for all radionuclide contaminants of potential concern, except Cs-137 and Pu-241 (see Table 6-29). Table 6-37 presents hazard quotients generated from internal and external exposures associated with Cs-137 and Pu-241 concentrations simulated in surface soil for the current scenario. Internal hazard quotients for all avian species and functional groups exceeded the target value of 0.1 for Cs-137. Hazard quotients for Cs-137 ranged from 0.2 for the bald eagle to 10 for avian herbivores, mammals, and reptiles. Hazard quotient values for Sr-90 ranged from 0.5 for the bald eagle to 25 for avian herbivores, all mammals, and all reptiles. External exposure hazard quotients for both Cs-137 and Pu-241 were well below the target of 0.1 for all receptors for the current scenario.

Table 6-37. Hazard quotients for internal and external radiological exposures from surface soil for the current scenario.

Receptor	Cesium-137		Plutonium-241	
	Internal	External	Internal	External
Avian herbivores (AV122)	10.0	<0.1	<0.1	<0.1
Peregrine falcon	2.5	<0.1	<0.1	<0.1
Bald eagle	0.2	<0.1	<0.1	<0.1
Loggerhead shrike	6.5	<0.1	<0.1	<0.1
Burrowing owl	2.5	<0.1	<0.1	<0.1
Mammalian herbivores (M122A)	10.0	<0.1	<0.1	<0.1
Pygmy rabbit	10.0	<0.1	<0.1	<0.1
Townsend's western big-eared bat	10.0	<0.1	<0.1	<0.1
Mammalian carnivores (M322)	10.0	<0.1	<0.1	<0.1
Sagebrush lizard	10.0	<0.1	<0.1	<0.1
Reptilian carnivores (R322)	10.0	<0.1	<0.1	<0.1
Plants	10.2	<0.1	<0.1	<0.1

Hazard quotient exceeds 0.1 for radionuclides.

Tables 6-38 and 6-39 present hazard quotients generated from internal and external exposures associated with concentrations of radionuclide contaminants of potential concern simulated in subsurface soil for the current and 100-year scenarios, respectively. Except for Ra-226 exposure to bald eagles, internal hazard quotients for Am-241, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Sr-90, U-234, and U-238 exceeded the target value of 0.1 for all receptors. In general, hazard quotient values for most receptors exceeded 1,000 for all contaminants except Ra-226, U-234, and U-238. The highest hazard quotients for all receptors were associated with Am-241, which ranged from 335 for the bald eagle to 18,600 for all avian, mammalian, and reptilian receptors. Hazard quotients for Am-241, Cs-137, and Sr-90 exceeded the target of 0.1 for all receptors for the current scenario, except the bald eagle. External hazard quotients for all other radionuclide contaminants were well below the target threshold of 0.1 for all receptors for the current scenario.

Simulated concentrations in surface soil for the current scenario were below ecologically based screening levels for all nonradionuclide contaminants (see Table 6-30). Table 6-40 presents hazard quotients generated from exposures associated with nonradionuclide concentrations simulated in subsurface soil for the current scenario. Hazard quotients for beryllium exceeded the target value of 1 for all mammalian herbivores, carnivores, and Townsend's western big-eared bat. Those hazard quotients ranged from 4 for mammalian herbivores to 38 for Townsend's western big-eared bat. Hazard quotients for cadmium exceeded the target value for all receptors, except the bald eagle, ranging from 2 for the peregrine falcon to 638 for Townsend's western big-eared bat. Lead concentrations resulted in hazard quotients that exceeded the target of 1 for three of the five avian receptors, ranging from 2 for the burrowing owl to 8 for the loggerhead shrike. The lead hazard quotient for Townsend's western big-eared bat was 3. Risk from all nonradionuclide contaminants of potential concern could not be evaluated for reptiles because no toxicity data existed with which to develop a toxicity reference value.

Table 6–38. Hazard quotients for internal and external radiological exposures from subsurface soil for the current scenario.

Receptor	Americium-241		Cesium-137		Plutonium-238		Plutonium-239		Plutonium-240		Plutonium-241		Radium-226		Strontium-90		Uranium-234		Uranium-238	
	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External[a]	Internal	External	Internal	External
Avian herbivores (AV122)	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1
Peregrine falcon	4,650	0.3	4,023	185.7	39	<0.1	1,571	<0.1	355	<0.1	116	<0.1	1.5	<0.1	160	2.4	1.4	<0.1	2.9	<0.1
Bald eagle	335	0.02	290	13.4	3	<0.1	113	<0.1	26	<0.1	8	<0.1	0.1	<0.1	11	0.2	0.1	<0.1	0.2	<0.1
Loggerhead shrike	12,090	0.7	10,460	482.7	100	<0.1	4,085	<0.1	924	<0.1	301	<0.1	3.8	<0.1	415	6.1	3.5	<0.1	7.4	<0.1
Burrowing owl	4,650	0.3	4,023	185.7	39	<0.1	1,571	<0.1	355	<0.1	116	<0.1	1.5	<0.1	160	2.4	1.4	<0.1	2.9	<0.1
Mammalian herbivores (M122A)	18,600	0.3	16,093	185.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	2.4	5.4	<0.1	11.4	<0.1
Pygmy rabbit	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1
Townsend's western big-eared bat	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1
Mammalian carnivores (M322)	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1
Sagebrush lizard	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1
Reptilian carnivores (R322)	18,600	1.1	16,093	742.7	154	<0.1	6,285	<0.1	1,421	<0.1	463	<0.1	5.8	<0.1	638	9.5	5.4	<0.1	11.4	<0.1

a. Includes external exposures for daughter products.

Hazard quotient exceeds the target value of 0.1 for radionuclides.

Table 6–39. Hazard quotients for internal and external radiological exposures from subsurface soil for the 100-year scenario.

Receptor	Americium-241		Cesium-137		Plutonium-238		Plutonium-239		Plutonium-240		Plutonium-241		Radium-226		Strontium-90		Uranium-234		Uranium-238	
	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External[a]	Internal	External	Internal	External[a]
Avian herbivores (AV122)	11,295	0.2	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Peregrine falcon	2,824	<0.1	96	44.2	18	<0.1	1,571	<0.1	351	<0.1	0.9	<0.1	1.4	<0.1	30	<0.1	1.1	<0.1	2.3	<0.1
Bald eagle	203	0.4	7	3.2	1.3	<0.1	113	<0.1	25	<0.1	<0.1	<0.1	0.1	<0.1	2.1	<0.1	0.1	<0.1	0.2	<0.1
Loggerhead shrike	7,342	0.2	249	115.0	46	<0.1	4,085	<0.1	913	<0.1	2.5	<0.1	3.6	<0.1	77	<0.1	2.8	<0.1	5.9	<0.1
Burrowing owl	2,824	0.2	96	44.2	18	<0.1	1,571	<0.1	351	<0.1	0.9	<0.1	1.4	<0.1	30	<0.1	1.1	<0.1	2.3	<0.1
Mammalian herbivores (M122A)	11,295	0.6	383	44.2	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Pygmy rabbit	11,295	0.6	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Townsend's western big-eared bat	11,295	0.6	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Mammalian carnivores (M322)	11,295	0.6	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Sagebrush lizard	18,600	0.6	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1
Reptilian carnivores (R322)	18,600	0.2	383	176.9	70	<0.1	6,285	<0.1	1,405	<0.1	3.8	<0.1	5.6	<0.1	118	<0.1	4.3	<0.1	9.1	<0.1

a. Includes external exposures for daughter products.

Hazard quotient exceeds the target value of 0.1 for radionuclides.

Table 6-40. Hazard quotients for exposures to nonradiological contaminants in subsurface soil for the current scenario.

Receptor	Beryllium	Cadmium	Lead
Avian herbivores (AV122)	NA	15	3
Peregrine falcon	NA	2	<1
Bald eagle	NA	<1	<1
Loggerhead shrike	NA	13	8
Burrowing owl	NA	3	2
Mammalian herbivores (M122)	4	514	<1
Pygmy rabbit	<1	186	<1
Townsend's western big-eared bat	38	638	3
Mammalian carnivore (M322)	17	507	<1
Sagebrush lizard	NA	NA	NA
Reptilian carnivores (R322)	NA	NA	NA

NA = not applicable. An appropriate toxicity reference value cannot be developed for this ecological contaminant of potential concern.

Hazard quotient exceeds the target value of 1 for nonradionuclides.

6.7.5.2.2   *100-Year Scenario*—Table 6-41 presents hazard quotients generated from internal and external exposures associated with concentrations of radionuclide contaminants of potential concern in surface soil for the 100-year scenario. Only concentrations of Am-241 and Cs-137 exceeded ecologically based screening levels for the 100-year scenario. Internal hazard quotients for all receptors, except the bald eagle, exceeded the target value of 0.1 for Am-241, ranging from 0.4 for the peregrine falcon and burrowing owl to 1.84 for avian herbivores and all mammalian and reptilian receptors. Internal hazard quotients for Cs-137 also exceeded 0.1 for all receptors, except the bald eagle. Hazard quotients for Cs-137 ranged from 1.7 for the peregrine falcon and burrowing owl to 6.9 for all other avian, mammalian, and reptilian receptors. For the 100-year scenario, external exposure hazard quotients for Am-241 and Cs-137 were well below the target of 0.1 for all receptors except plants.

Table 6-39 presents hazard quotients generated from internal and external exposures associated with concentrations of radionuclide contaminants of potential concern in subsurface soil for the 100-year scenario. Hazard quotients for Am-241, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Sr-90, U-234, and U-238 exceeded the target value of 0.1 for all receptors (with the exception of bald eagle exposures to Ra-226 and Pu-241). The highest hazard quotients for all receptors were associated with Am-241 (ranging from 203 for the bald eagle to 18,600 for reptilian receptors), Pu-239 (ranging from 113 for the bald eagle to 6,285 for avian herbivores and all mammalian and reptilian receptors), and Pu-240 (ranging from 25 for the bald eagle to 1,450 for avian herbivores and all mammalian and reptilian receptors). Hazard quotients for the other contaminants ranged from 0.1 (Ra-226) to 118 (Sr-90). With the exception of bald eagle exposures to Am-241, external exposure hazard quotients for Am-241, Cs-137, and Sr-90 (as a result of emissions by daughter products) also exceeded the target of 0.1 for all receptors for the 100-year scenario. External hazard quotients for all other radionuclide contaminants were well below the target of 0.1 for all receptors for the 100-year scenario.

Table 6-41. Hazard quotients for internal and external radiological exposure from surface soil for the 100-year scenario.

Receptor	Americium-241		Cesium-137	
	Internal	External	Internal	External
Avian herbivores (AV122)	1.8	<0.1	6.9	<0.1
Peregrine falcon	0.4	<0.1	1.7	<0.1
Bald eagle	<0.1	<0.1	<0.1	<0.1
Loggerhead shrike	1.1	<0.1	4.5	<0.1
Burrowing owl	0.4	<0.1	1.7	<0.1
Mammalian herbivores (M122A)	1.8	<0.1	6.9	<0.1
Pygmy rabbit	1.8	<0.1	6.9	<0.1
Townsend's western big-eared bat	1.8	<0.1	6.9	<0.1
Mammalian carnivores (M322)	1.8	<0.1	6.9	<0.1
Sagebrush lizard	1.8	<0.1	6.9	<0.1
Reptilian carnivores (R322)	1.8	<0.1	6.9	<0.1
Plants	1.3	<0.1	130	0.2

Hazard quotient exceeds the target value of 0.1 for radionuclides.

Table 6-42 presents hazard quotients generated from exposures associated with concentrations of nonradionuclide contaminants of potential concern for the 100-year scenario. Hazard quotients for beryllium exceed the target value of 1 for all mammalian receptors and plants. Hazard quotients for cadmium exceed the target for two of the five avian receptors and all mammalian receptors, with hazard quotients ranging from 6 for the loggerhead shrike to 275 for Townsend's western big-eared bat. Lead concentrations result in hazard quotients that exceed the target of 1 for four of the five avian receptors, ranging from 4 for the peregrine falcon to 26 for the loggerhead shrike. Hazard quotients for lead also exceed the target for Townsend's western big-eared bat, mammalian carnivores, and plants.

6.7.6 Ecological Risk Evaluation

All 16 radionuclide contaminants of potential concern identified in the Waste Area Group 7 preliminary screening were evaluated in this assessment. Eight of 40 nonradionuclide contaminants of potential concern were evaluated as indicators of potential risk for this group of contaminants (see Section 6.7.2). Table 6-43 lists 31 nonradionuclide contaminants of potential concern that were not specifically analyzed in this assessment.

The assessment endpoint for the Waste Area Group 7 ecological risk assessment was the indication of risk to ecological receptors, determined by hazard quotient values that exceeded target values for either the current or 100-year scenario. More conservative assumptions incorporated in the biotic model regarding contaminant release (see Section 5.5) resulted in hazard quotients three to four orders of magnitude higher than those calculated for the ABRA (Holdren et al. 2002).

Table 6-42. Hazard quotients for exposures to nonradiological contaminants in subsurface soil for the 100-year scenario.

Receptor	Beryllium	Cadmium	Lead
Avian herbivores (AV122)	NA	6	10
Peregrine falcon	NA	<1	4
Bald eagle	NA	<1	<1
Loggerhead shrike	NA	6	26
Burrowing owl	NA	<1	6
Mammalian herbivores (M122)	4	221	<1
Pygmy rabbit	<1	80	<1
Townsend's western big-eared bat	38	275	9
Mammalian carnivores (M322)	16	218	4
Sagebrush lizard	NA	NA	NA
Reptilian carnivores (R322)	NA	NA	NA
Plants	4	<1	2

Hazard quotient exceeds the target value of 1 for nonradionuclides.

Table 6-43. Contaminants not specifically evaluated in the ecological risk assessment.

1,1,2-trichloro-1,2,2-trifluoroethane	Organophosphates (tributylphosphate)
1,4-dioxane	Potassium chloride
3-methylcholanthrene	Potassium dichromate
Alcohols	Potassium hydroxide
Aluminum nitrate	Potassium nitrate
Dibutylethylcarbutol	Potassium phosphate
Ether	Potassium sulfate
Ethyl alcohol	Sodium chloride
Hydrofluoric acid	Sodium cyanide
Lithium hydride	Sodium nitrate
Lithium oxide	Sodium phosphate
Magnesium oxide	Sodium-potassium
Manganese	Sulfuric acid
Nitrobenzene	Trichloroethylene
Nitrocellulose	Trimethylpropane-triester
Nitric acid	Versenes (EDTA)
Organic acids (ascorbic acid)	Xylene

EDTA = ethylenediaminetetraacetic acid

Contaminants for which data are inadequate to allow quantitative analysis (Hampton and Becker 2000).

The contaminants in Waste Area Group 7 shown to pose risk to ecological receptors (i.e., hazard quotients greater than 10 times the target value [DOE-ID 1999]) include Am-241, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Sr-90, U-234, U-238, beryllium, cadmium, and lead. Risk to ecological receptors is concentrated in the subsurface soil profile for the scenarios evaluated. Surface soil concentrations of Am-241, Cs-137, and Pu-241 also pose current and future risk to ecological receptors. Plant uptake and burrowing by animals were shown to increase current subsurface soil concentrations for Sr-90 and Cs-137 above adverse levels during the next 100 years.

Subsurface soil concentrations peaked for all contaminants, except beryllium, during the current scenario (see Table 6-31). While risks to ecological receptors, posed by subsurface soil contaminants, generally are decreasing, concentrations for all 13 contaminants remained at levels expected to pose risk to ecological receptors up to and beyond the 100-year simulated institutional control period (i.e., the year 2110).

Surface concentrations for Pu-241 and cadmium that pose risks to ecological receptors were reached during the modeled scenarios, but leaching reduced cadmium concentrations below levels expected to pose risk to ecological receptors before the year 2010. Maximum surface concentrations for Cs-137 pose risk to ecological receptors during the current scenario (see Table 6-31), and though still posing risk beyond the 100-year scenario, concentrations decreased before the end of the modeled period (the year 3002). Surface concentrations for Sr-90 began decreasing in the 100-year scenario without reaching adverse levels. Surface concentrations for Pu-238, U-234, and U-238 that could pose risk to receptors were exceeded beyond the institutional control period, but decreased without reaching adverse levels within the modeled period (before the year 2500). Adverse surface concentrations for Pu-239, Pu-240, and lead persisted beyond the year 3002. Though Ra-226 concentrations increased through the modeled period, adverse levels were not reached.

Though modeled soil concentrations were not quantitatively compared to sampling data for this assessment, a cursory examination of concentrations in biotic tissue in and around the SDA shows that concentrations of Am-241 are much higher in plant and animal tissue than are concentrations of Pu-239 and Pu-240 (see Section 4.13). In general, monitoring data are consistent with the predicted trend of higher hazard quotients for Am-241 than for Pu-239 and Pu-240. Human health sampling data were not compared to modeled concentrations for this assessment, and no biotic data were collected for these contaminants in the SDA.

Current risk from surface and subsurface contamination is identified with 13 ecological contaminants of potential concern, and, without remedial action, risk will continue beyond the 100-year simulated institutional control period. Risks for nonradionuclide contaminants of potential concern presented in Table 6-43 were not evaluated. Simulated surface concentrations for several contaminants were shown by the model to increase with time, in some cases beyond the modeled period (see Table 6-31). Results suggest that in the absence of remediation to control current intrusion by biotic receptors, risk over the long term may increase above levels identified in this screening-level assessment.

6.8   Baseline Risk Assessment Summary

The human health risk assessment evaluates residential and occupational exposure scenarios to estimate baseline risk (i.e., risk in the absence of remedial action). Residential risks are bounding. For residential scenarios, 18 contaminants within the 1,000-year simulation period have cumulative risk greater than or equal to 1E-05, a hazard index greater than or equal to 1, or simulated groundwater concentrations that exceed MCLs. For eight additional contaminants, residential risk estimates are greater than or equal to 1E-05, or simulated groundwater concentrations are greater than MCLs within the 10,000-year simulation period.

In the 1,000-year simulation period, highest residential risks are driven by biotic uptake and surface pathway exposure from Am-241, Cs-137, Pb-210, Pu-239, Pu-240, Ra-226, Ra-228, Sr-90, Th-228, and trichloroethylene. Risks from I-129, 1,4-dioxane, and nitrate are primarily through groundwater pathway exposures; risks from C-14 and carbon tetrachloride are through groundwater and vapor inhalation exposure at the surface, while risk from Tc-99 is through groundwater ingestion and irrigating crops with groundwater. Simulated groundwater concentrations exceed MCLs for I-129, Tc-99, carbon tetrachloride, 1,4-dioxane, methylene chloride, nitrate, and tetrachloroethylene.

Figure 6-126 shows total risk over time and relative contributions attributable to each exposure pathway for the future residential scenario. Except for inhalation of volatiles, risk remains greater than 1E-05 for each exposure pathway throughout the 1,000-year simulation period, and cumulative risk remains well above 1E-03. External exposure and soil ingestion dominate the risk. Crop ingestion risk initially is high after institutional control. Inhalation is less than 1E-05 immediately after institutional control but increases rapidly. Volatile inhalation risk is slightly greater than 1E-05 at the end of institutional control but decreases to less than 1E-05 within 50 years. Figures 6-127 through 6-131 illustrate individual pathway risks for surface exposure pathways over 1,000 years. Each figure shows the total by pathway, the major contributors to the total, and the sum of the other contaminants. These plots supplement the individual contaminant plots shown in Section 6.4.2.2.
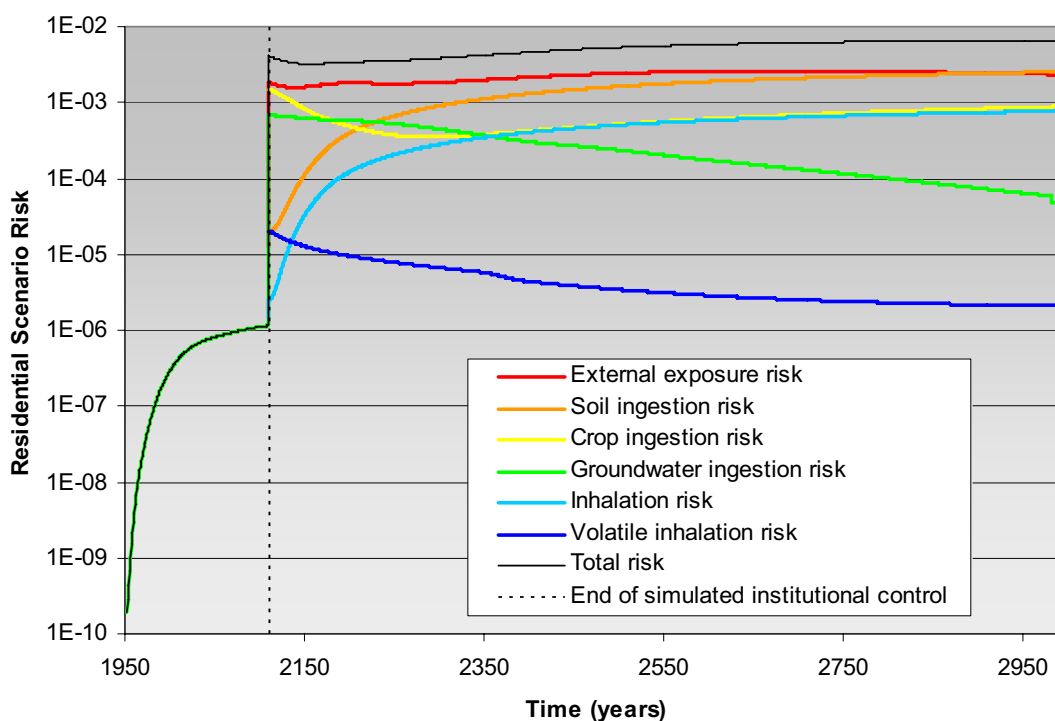

Figure 6-126. Total residential exposure scenario risk by exposure pathway for all radionuclides and nonradionuclides.
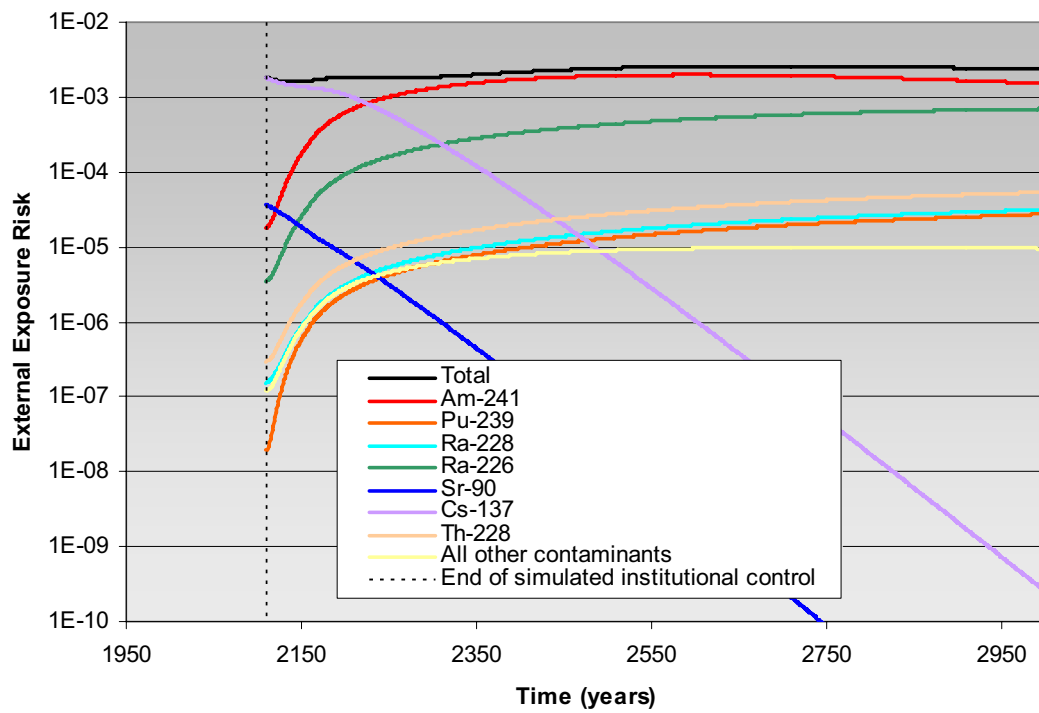
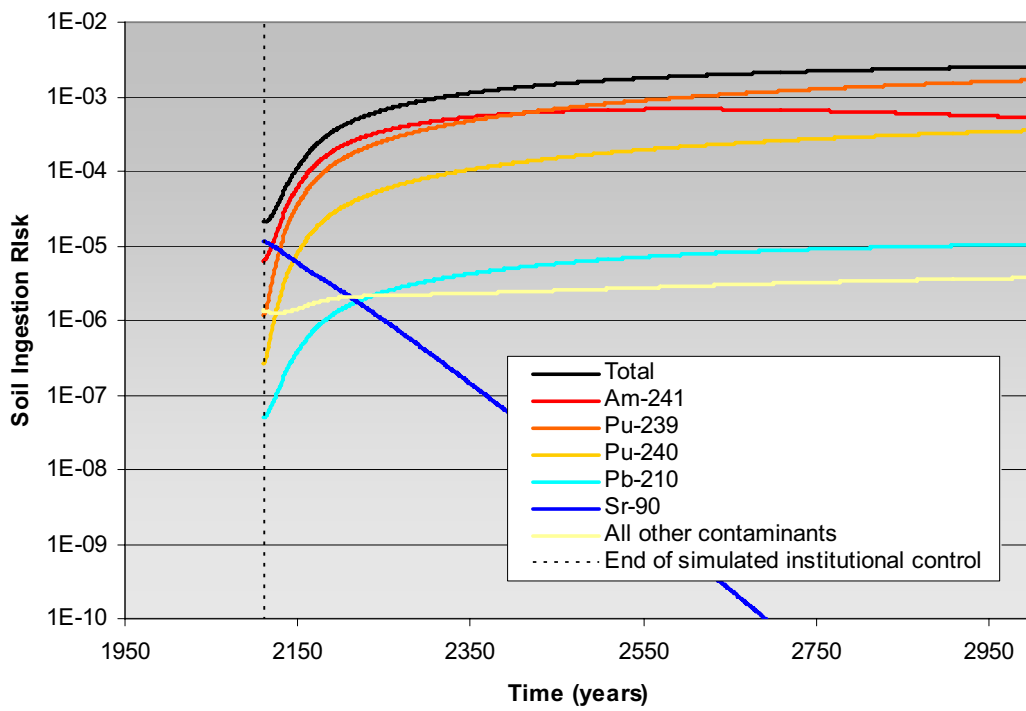Figure 6-127. Major contributors to external exposure risk.

Figure 6-128. Major contributors to soil ingestion risk.
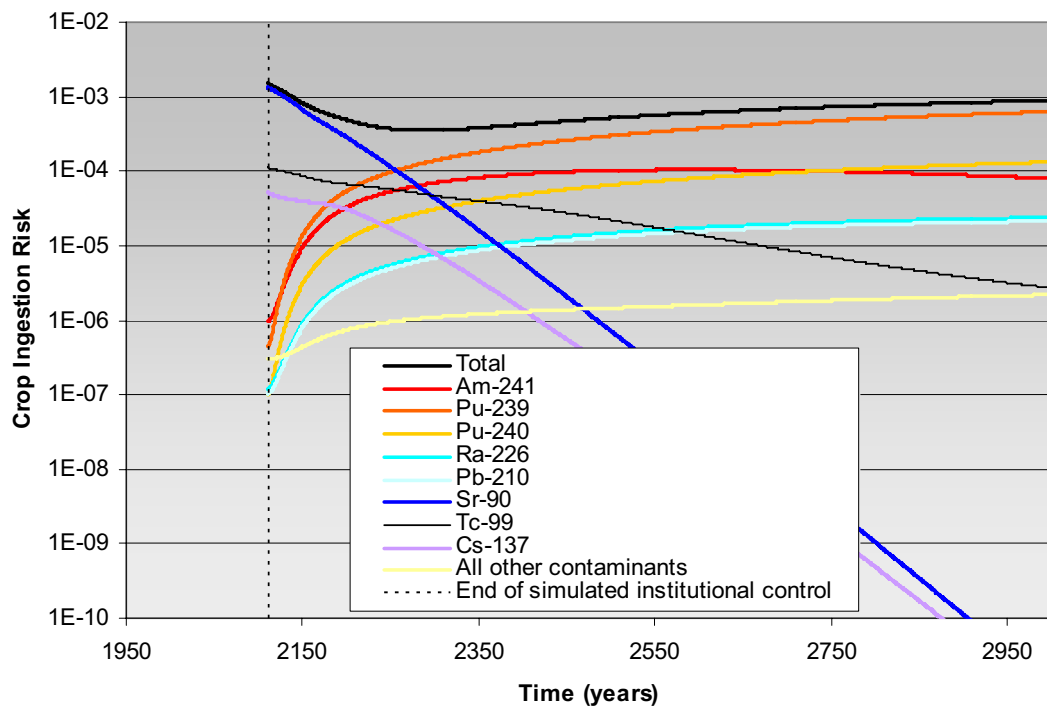
Figure 6-129. Major contributors to crop ingestion risk.
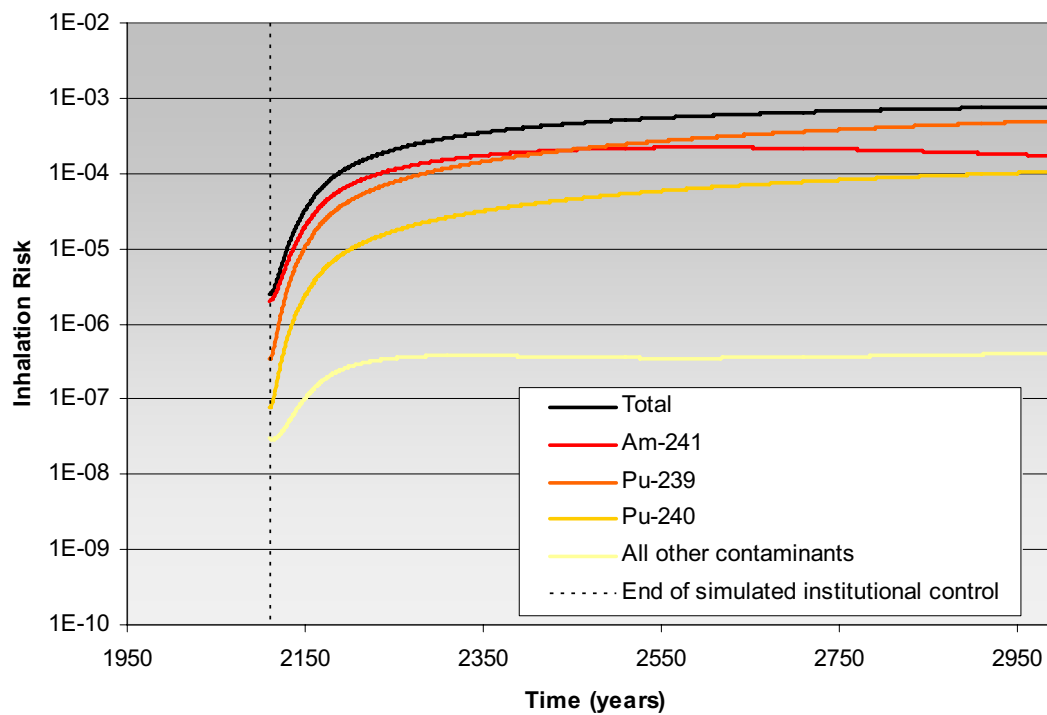
Figure 6-130. Major contributors to inhalation risk.
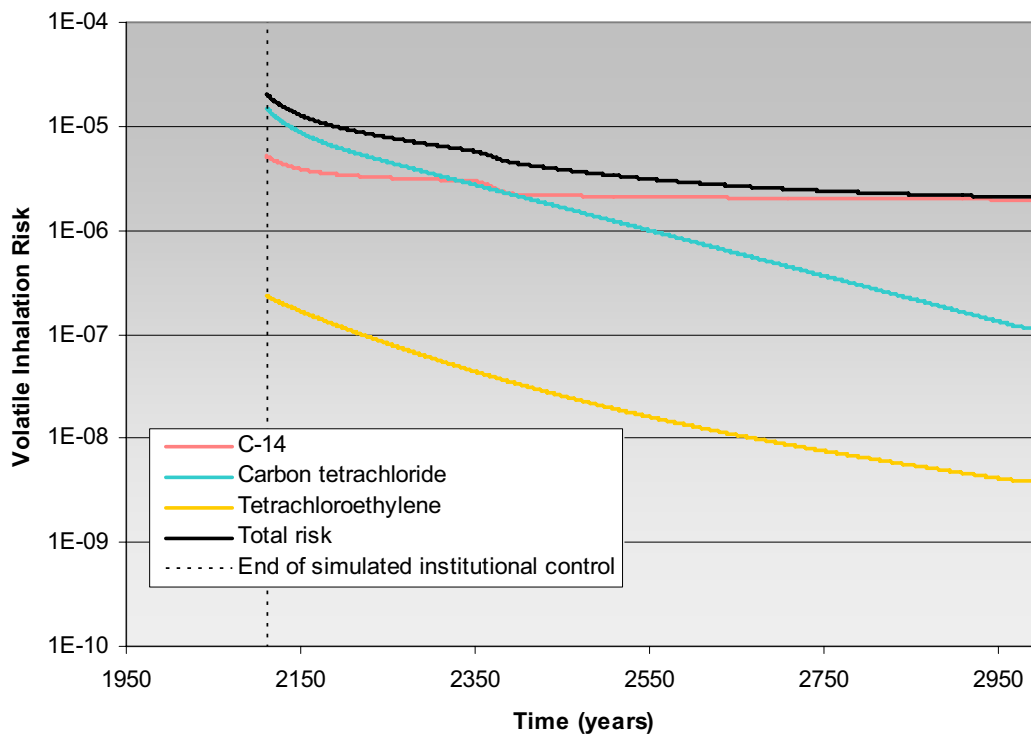
Figure 6-131. Major contributors to volatile inhalation risk.

Groundwater ingestion risk was simulated over 10,000 years. Figure 6-132 shows total 10,000-year groundwater ingestion risk for all radionuclides and nonradionuclides, major contributors to the total, and the sum of the other contaminants. Groundwater ingestion risk immediately after the end of institutional control is driven by carbon tetrachloride and Tc-99. Groundwater ingestion risk drops after the 1,000-year simulation period (the year 3010); VOC simulations were stopped at that point because simulated concentrations for VOCs were decreasing rapidly. Groundwater ingestion risk after 1,000 years is primarily from Np-237 and U-238, though risk from Ac-227, Pa-231, U-233, U-234, U-235, and U-236 each exceed 1E-05 within 10,000 years. Within the 1,000-year simulation, eight contaminants exceed their respective MCLs: I-129, Tc-99, carbon tetrachloride, 1,4-dioxane, methylene chloride, nitrate, tetrachloroethylene, and trichloroethylene. In the 10,000-year simulations, MCLs are exceeded for Np-237, U-238, and total uranium because of U-238. Groundwater risk estimates for Tc-99 and I-129 are based on modeling assumptions that may not appropriately represent conditions. Concentrations measured for Tc-99 in the vadose zone and aquifer are a factor of two orders of magnitude less than modeling predicts.

Figure 6-132. Major contributors to groundwater ingestion risk.

Parametric sensitivity and qualitative uncertainty analyses were performed for those parameters identified by DOE, DEQ, and EPA as important for understanding uncertainty in base-case risk. The sensitivity analysis shows the effect on predicted risk of changes in selected model inputs. With the exception of inventory sensitivity, sensitivity analysis focused on the groundwater ingestion pathway. Sensitivity cases are summarized in the following list:

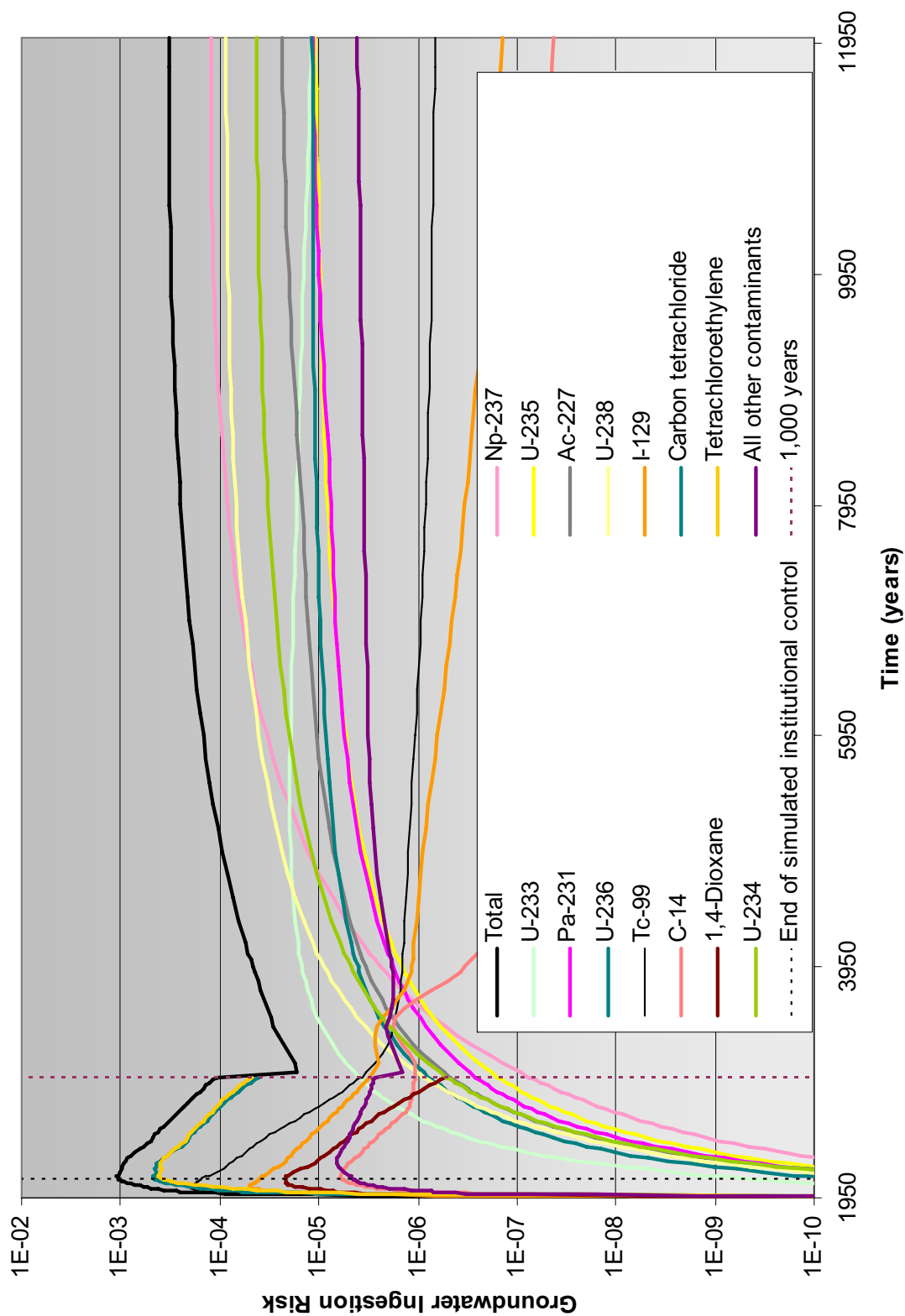- **Inventory**—To assess sensitivity to source-term inventory, risk was estimated based on upper-bound inventories. Risk estimates for most contaminants were of the same order of magnitude, with total cumulative risk for all contaminants higher by an approximate factor of 2.

- **Infiltration**—Three sensitivity cases addressing infiltration rates were examined: (1) reduced background infiltration outside the SDA, (2) low infiltration inside the SDA, and (3) high uniform infiltration inside the SDA. Reduced background infiltration produced slightly higher risk estimates, while lower and higher infiltration inside the SDA paralleled lower and higher risk.

- **Interbed gaps**—The effect of neglecting known gaps in the B-C interbed was evaluated by completely eliminating the B-C interbed in the model; negligible effect was noted.

- **Pit 4 retrieval and beryllium block grouting**—Because the base case incorporated assumptions that beryllium blocks would be grouted and the targeted retrieval in Pit 4 would be completed, a sensitivity case was performed to examine consequences of not completing these remedial actions. A slight increase in C-14 groundwater ingestion risk was noted in the absence of grouting. For retrieval, groundwater risk does not change if the retrieval in Pit 4 is not completed. Except for carbon tetrachloride, Rocky Flats Plant contaminants do not drive groundwater risk. The retrieval area contains only a small fraction of carbon tetrachloride.

- **Low permeability zone**—Effects of the postulated low-permeability zone assumed for the base case were evaluated by implementing a sensitivity case that did not include such a region in the aquifer. In the absence of a low-permeability zone, risk estimates are substantially lower (e.g., decrease from 3E-04 to 4E-05 for radionuclides, excluding Tc-99 and I-129), further suggesting that base-case model results are conservative.

- **No sorption in interbeds**—Removing the effects of plutonium sorption in interbed sediment was evaluated by completely eliminating sorption in the B-C and C-D interbeds using an approach roughly equivalent to spreading the plutonium source term into a thin layer (i.e., by advective spreading in the vadose zone) and leaching it directly into the aquifer. Results of this extremely conservative simulation show increase in risk by several orders of magnitude.

The intruder scenario quantified the effect of a hypothetical well driller intruding into waste in the SDA. The chosen scenarios evaluate drilling into the most highly contaminated areas of the SDA. Analysis shows that intrusion into waste containing a high concentration of gamma-emitting nuclides could pose an external exposure risk of 4E-04 attributable to Cs-137. Risk estimates for all other gamma emitters are well below 1E-06. Risk from drilling a well into high concentrations of alpha-containing waste is less than 1E-06.

Waste Area Group 7 contaminants posing risk to ecological receptors are Am-241, Cs-137, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Sr-90, U-234, U-238, beryllium, cadmium, and lead. Risk to ecological receptors is concentrated in the subsurface soil profile (i.e., depth interval from 0.15 to 3 m [0.5 to 10 ft]) for the scenarios evaluated. Surface soil (defined as the uppermost 0.15 m [0.5 ft]) concentrations of Am-241, Cs-137, and Pu-241 also pose current and future risk to ecological receptors.

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